

Innovative jacquard textile design using digital technologies

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Innovative jacquard textile design using digital technologies

Frankie Ng and Jiu Zhou



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Key terms and definitions

1. Single-plane design mode

A method of designing jacquard fabric based on one-to-one corresponding principle of which one specific woven structure is used to realise one corresponding colour in a 2D pattern. The limited number of colour expressions on the face of jacquard fabric produced by this method makes the jacquard fabric design easy to copy.

2. Layered-combination design mode

A method of designing jacquard fabric by combining several single-layer fabric structures that enable the jacquard fabric to express rich mixed colours up to mega level. The random and exclusive combined structural effects of jacquard fabric produced by this mode make it difficult to copy without the original design data. Moreover, even when the same weaves are being used to design individual single-layer fabric structures, the different motifs of image being employed make the colour number on the face of the fabric vary after structural combination.

3. Colourless design mode

A method of designing a single-layer fabric structure by the layer-combination design mode that is based on the brightness of grey-scales in the digital image: this is compatible with computer-programmed processing. The digital image applied for design should be in grey-scale mode without any colour information. Taking the brightness as standard, the grey-scale of an image can be replaced by corresponding gamut weaves.

4. Colourful design mode

A method of designing a compound fabric structure by the layer-combination design mode, by combining and arranging several single-layer fabric structures in a prescribed manner: a multicoloured effect of jacquard fabric will be obtained.

5. Gamut weaves

A series of weaves devised from a primary weave through an increase or decrease of its interlacing points. The interlacing points can be changed in various manners (number and/or position). When the changing number of interlacing points is one between the two adjacent weaves, the maximum weave number of gamut weaves results, whereas when the changing number of interlacing points is equal to the value of weave repeat between the two adjacent weaves, a minimum weave number of gamut weaves results.

6. Full-colour compound structure

A compound structure created by the layered-combination design mode that features unique full-colour structural effect. Since the juxtaposed threads employed in such a compound fabric structure are not covered by other threads, the jacquard fabric produced with this compound structure with different floating thread lengths exhibits a kind of full-colour effect.

7. Colour shading effect

A colour changing effect derived from the effect of printed textiles. It exhibits smooth gradation of two or more colours. In cases where the shading is produced by primary colours, e.g. cyan, magenta or yellow with black, a spectrum colour shading effect will be achieved.

8. Simulative effect

A jacquard fabric effect that aims to imitate an existing image. The simulated effect of traditional jacquard fabric achieved by the single-plane design mode has always been regarded as the highest technique-based design creation in jacquard fabric design. In this book, 'black-and-white simulative fabric' refers to a fabric constructed with black and white threads to imitate an achromatic image, and 'colour simulative fabric' refers to a fabric constructed with multicoloured threads to imitate a polychromatic image.

9. Innovative effect

A kind of jacquard fabric effect that aims to innovate (new woven art form) rather than to simulate. The colour and pattern of the innovated effect are different from those of the jacquard fabric designed under the traditional single-plane design mode.

10. True-colour effect

A term borrowed from computer terminology. It is used in this study to refer to a multicoloured effect jacquard fabric in which the number of mixed colours on the face of the fabric can be as high as a mega level (in theory).

11. Figured shot-effect

An iridescent effect of jacquard fabric design, created by the layered-combination design mode in which both the shot-effect and the figured effect are being exhibited at the same time.

12. Figured double-face effect

An innovation effect of jacquard fabric created by the layered-combination design mode where both the face and the reversed sides of a jacquard fabric are capable of expressing independent figured effect/image.

This exciting book of textile design proposes a layered-combination design method for jacquard textile creation from colourless mode (single-layer structure) to colourful mode (compound multi-layer structure) that differs from the traditional plane design method in that the mixed colour number on the face of the created digital jacquard fabric could be up to mega level in theory. The design concept, principles and methods proposed in this book offer originality and great significance for the innovation of jacquard fabric design method. This book presents the theoretical research, practical research and design application in an organised and progressive manner through which the development of digital jacquard textiles is deliberated.

The history and background of jacquard fabric is described through to the evolvement of digital jacquard technology and digital jacquard textile design, and two typical structural design methods of multi-coloured fabric, namely Chinese brocade and Western tapestry, are introduced. With rich literature cited, the limitations and deficiencies of existing design methods for fabric structure, e.g. the colour expression and the balanced interlacement, are identified.

The practice-led procedures adopted in this study are particularly suitable for approaching the design method research. The key theoretical and practical issues related to designing fabric structure under the layered-combination design method have been identified and tackled scientifically in Chapters 3 and 4. The design method of full-colour compound structure has been invented through a series of design experiments and analyses. This new method enables the number of mixed colours exhibited on the face of the jacquard fabric to be increased up to mega level, accurately, whereby smooth colour shading with multi-coloured effects can be produced. These achievements are of tremendous benefit to both the simulative and innovative design creations of digital jacquard presented in Chapters 6 and 7.

The design creations under the layered-combination design method proposed in this book are superior in comparison with traditional jacquard fabric. Three methods for designing black-and-white simulative effect fabric and two methods (basic design method and variant design method) for colourful simulative effect fabric are proposed in this book. Two design

methods for innovative effect fabrics are also introduced. For example, the figured-shot effect shows contrasting figure and contrasting colour effects at the same time, while figured double-face effect jacquard fabric shows full-colour figured effects independently on both sides of the fabric that is stitched by regular stitch weaves. Selected examples of design applications presented in Chapter 8 show an expanded creative dimension of jacquard textile design, and highlight the merit of the layered-combination design mode as well as the significance of the study explained in this book. Chapter 9 of this book concludes the study and summarises the results through a tabular comparison between traditional and digital jacquard textile design. It also suggests useful directions for further research on digital jacquard textile design.

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Introduction to jacquard textile design

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Abstract: This chapter provides a broad outline of the book, including a general background to the subject, presentation of objectives, corresponding methodologies, and the significance and value of the application of digital technologies to bring innovation to the design and production of jacquard fabric.

Key words: digital, jacquard, woven, fabric, layered-combination.

1.1 Introduction

Jacquard textile weaving is an ancient craft with a centuries-old history. The design and production of jacquard textiles has always been regarded as tedious and time-consuming endeavours, in which considerable skill and experience are required to produce hand-drawn patterns to form figured woven fabric. Due to the intricacy and unique design of the woven colours and patterns, jacquard textiles and related jacquard products have extended their applications to a wide range of fashion materials, home furnishings and decorations. Today, with the increase in demand for sophisticated and high-quality jacquard textiles, jacquard products made by conventional methods are often of a relatively crude quality and no longer satisfy consumer aspirations. It is imperative that more sophisticated and intricate designs are produced, with added commercial and artistic value. Digitisation technology and the digital design concepts proposed in this book are proving to be effective and powerful tools to achieve this goal.

Theoretically, a basic difference exists in the effect of colour and pattern between jacquard woven fabrics and printed fabrics. For printed fabrics, the printed pattern is a result of superimposing several transparent colour inks. Such superimposition of transparent inks enables a pattern to be reproduced on fabric with over a million shades. Hence, the pattern reproduced is very close to its original. For jacquard fabric as well as for woven fabric, however, pattern is reproduced through a kind of woven figuration, where the colour and pattern effect are dependent on the woven structure of interlacing warp ends and weft picks. Due to the different colour theories and restrictions of woven structures, the pattern of jacquard fabric ought to be designed with reference to the weaving and figuring technical conditions, such as fabric density, materials, the hook number, and the manner of

mounting of the jacquard machine. In addition, since the structure design of jacquard fabric is approached in a traditional single-plane design mode, and a one-to-one corresponding principle, i.e. designing weave one by one according to the effect of each colour drawn on a certain pattern, currently the colour expression of jacquard fabric is limited to not more than 100 colours in each pattern design (Zhou *et al.*, 2006). Even by employing CAD systems today, the design principles and processes are still subjected to a plane design mode. Thus, the colour and pattern effects of jacquard fabric remain very much the same in terms of expression. It is still a major challenge and aspiration for jacquard textile designers to be able to design a method that enables the creation of print-like patterns on figured woven fabrics that can be processed and produced conveniently on an industrial scale.

Today, digital image design is one of the popular design tools that merge technology and design, and it represents an important movement in the history of modern design. Capitalising on digitisation technology, digital image design features higher efficiency in design processing and greater compatibility in design applications. The effects produced by digital images can be more picturesque and imaginative than those expressed freehand. Thus, digital images fulfill very well the increased demands for innovation and novelty in the fast-moving commercial design industry. Due to its popularity, substantial investment and resources have been put into digital imaging technology, notably, for example, in the movie-making industry. It was therefore only a matter of time before digital design technology brought innovation to the design and production of jacquard textiles. Over the past ten years, for example, research had been carried out to study computer-aided design via digitisation technology, with the purpose of enhancing the design efficiency of jacquard fabric. However, because of the unresolved constraints of plane design mode, the design of jacquard textiles has remained unchanged and digital image design, via CAD, has been employed only to replace hand-drawn patterns and point papers; digital technology was not directly applied to the creation of jacquard textile designs *per se*. Since the structural design of the fabric plays the most important role in the creation of jacquard textiles, an attempt has now been made, in this book, to bring innovation to the traditional principles and methods of structural design through the deployment of digitalisation technology.

In addition to structure design, the colour theory of woven fabric is another important factor in the innovation of jacquard fabric. In colour science, colours are a result of colour mixing of the three primary colours. For colour mixing, three theories prevail: the additive colour mixture of light, the subtractive colour mixture of pigment, and optical colour mixture. For jacquard fabric, as well as for woven fabrics constructed with opaque

colour threads, the resultant colour effect exhibited on the face of the fabric is subject to optical colour mixing. By tradition, jacquard fabric design is a mechanical reproduction under a single-plane design mode that aims to imitate the colour and pattern effects of hand paintings. The potential aesthetic innovation of colour and figuration of the woven structure of the fabric have largely been overlooked and underexplored. Having said that, the potential artistic and commercial value of innovative design and production of jacquard textiles remains a fertile field of research.

1.2 The use of digital technologies in jacquard textile design

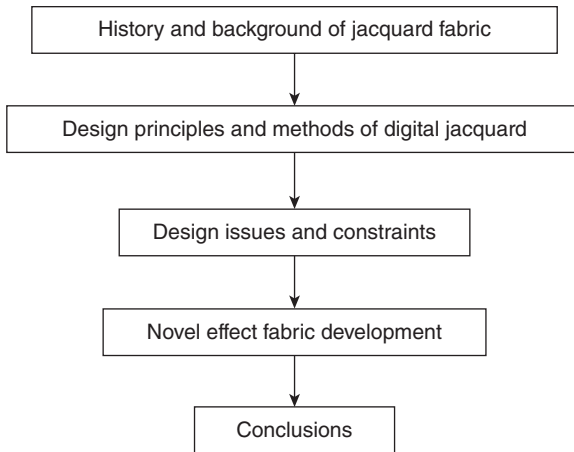
Digital textile design is one of the most important research directions in advanced textile technology and science. Development of innovative textile products is of both artistic and commercial value. At present, research in digital printed textiles attracts global interest and has yielded fruitful results in commercial applications. By contrast, research in digital jacquard textile is still in its developing stage, due partly to the complication of the digitisation processing for a woven structure. Since jacquard fabric is interwoven with warp and weft threads, the colour and pattern effect of jacquard fabric can only be realised through its woven structure. Innovation in fabric structure is thus crucial to future design innovation of jacquard fabric. To this end, the research reported in this book aimed to invent new design concepts, principles and related design methods in jacquard textile design and production via the deployment of digitisation technology. The specific objectives of the application of digital technologies for innovating jacquard fabric are listed below.

1. To re-invent the concept, methods and procedures of jacquard textile design using digitisation technology to replace the traditional single-plane design mode.
2. To explore and expand the creative dimension of woven textile structures and their colour expression based on digital design principles and methods.
3. To investigate optimal structural design methods in accordance with the layered-combination design mode.
4. To construct a theoretical framework for design creation of digital jacquard fabric, in which a series of weave-databases are established with which design and production of digital jacquard fabric, under varied processing conditions and fabric technical parameters, are made possible.
5. To create sample jacquards to illustrate and explain the simulative and innovative effects of digital jacquard textile design.

The design concept of digital jacquard was originally borrowed from the 'layered-combination' design method of digital images. In theory, a colour digital image is displayed in the form of the colour mixture effect of primary colours, each with its individual colour path/channel. Since a digital image can be separated into several colourless layers through colour separation, attempts have been made in this book to translate the design concept and principle of the digital image into the digitisation processing of jacquard fabric design. The result is an innovative design method, called the 'layered-combination' design mode, which is proposed in this book and which enables innovative jacquard textile design and production. In general, the layered-combination design mode consists of two parts: a colourless mode and a colourful mode. The design of colourless digital jacquard is based on the grey-scale mode of digital colour and single-layer woven structures. By using the layered-combination design method, several colourless single-layer structures can be combined to form a compound structure that enables the production of true-colour effect jacquard fabric with millions of colour shades. By employing an innovative design method of full-colour compound structures, invented especially for the layered-combination mode, the jacquard fabrics created are capable of expressing picturesque and print-like effects with smoother colour gradation. Several designed images have been specially created for this book to illustrate the thrust of the proposed new design concepts, both in the layered-combination design mode for digital jacquard fabric design and the related full-colour structure design method. Two directions were proposed for design creation: simulative effect and innovative effect. The former enables the simulation of both black-and-white and colourful effects, whilst the latter enables the creation of various original effects including a figured shot-effect and a figured double-faced effect.

Figure 1.1 presents a flow-chart of the organisation of research for this project. Research was organised in five stages: (i) the history and background of jacquard fabric; (ii) design principles and methods of digital jacquard; (iii) design issues and constraints; (iv) novel simulative and innovative effect fabric development; and (v) conclusions.

In the initial stage, a literature review of the history and background of jacquard fabric was conducted. Comparisons of design concepts, principles and methods between traditional jacquard fabric and digital jacquard fabric were made. The second and third stages were crucial, and involved detailed theoretical and practical research using digital technologies, during which theoretical design and practical realisation of new jacquard structures was undertaken. In these stages, based on the principles of digital image design and digital colour theory, the 'layered-combination design mode' was theorised and proposed for digital jacquard fabric creation. The design mode was further evaluated from theory to practice. Practical research was divided



1.1 Key steps in research into innovative jacquard textile design.

into colourless and colourful streams in which key design issues and constraints, and related optimal solutions, were introduced. ‘Colourless’ and ‘colourful’ referred not only to the subsequent colour effect of the fabrics, but also to the design mode by which digital jacquard was designed and created. The fourth stage of study targeted the development of novel effect specimens that testify to the validity of the proposed concept, principles and methods of the layered-combination design mode. The design specimens created in this stage illustrated both the simulative and innovative effects produced under lower warp density (see Appendix 2, section A2.1) as well as higher warp density (see Appendix 2, section A2.2) (Zhou, 2001). In the final stage, conclusions were drawn, limitations identified and further work in this area recommended.

This book’s main contribution is not only the proposed design concepts, principles and methods that are particularly suitable for the digitisation processing of the sophisticated structural design of jacquard textiles, but also the provision of detailed design illustrations and technical parameters for digital jacquard, created for ease of reproduction. For thousands of years, jacquard textiles have been designed and produced in a single-plane design mode, mechanically reproducing the colour and pattern effects of hand paintings. The new theoretical concept of digital jacquard proposed here merges digital design technology into jacquard textile design, and has made it possible to design and produce jacquard textiles directly from digital images. The digital jacquard textiles produced in this way are capable of exhibiting fabric effects far beyond those that traditional jacquard fabric can express.

During the study undertaken for this book, a layered-combination design mode for digital jacquard textile was proposed. With reference to the design principle of the digital image, and in particular to digital colour theory, the number of colours expressed on the face of a fabric can now be at a mega level. This study has succeeded in inventing a new concept and method of digital jacquard textile design, giving rise to a number of original effects. The originality of the present research lies in the establishment of a new concept, principles and methods of digital jacquard textile design and production. It involved an innovative layered-combination design mode and a related unique structural design method by which novel effect jacquard fabrics can be created. In short, the results of the application of digital technologies provide a brand new concept for the innovation of colour and structural design of jacquard fabrics that should have a significant influence on their future creation and development. The innovations allow for the digitisation of jacquard fabric structure and fabric creation, expanding the creative and aesthetic dimensions of jacquard textiles, with major impacts on costs and production lead-times.

1.3 The organisation of this book

This first chapter provides a broad outline of the book, including a general background to the subject, presentation of objectives, corresponding methodologies, and the significance and value of the application of digital technologies to bring innovation to the design and production of jacquard fabric.

Chapter 2, 'The development of jacquard fabrics and textile design methods', introduces the history of jacquard, including a discussion of the features of jacquard textiles and the evolution of jacquard fabric design. Chinese brocade and Western tapestry, two representative traditional (pre-digitisation) design methods for figured colourful woven fabrics, are presented and analysed in depth, in order to illustrate the difference in design principles and methods between the design of traditional jacquard fabric and more contemporary digital jacquard fabric.

Chapter 3, 'Principles and methods of digital jacquard textile design', lays the theoretical foundation for using digital technologies to design jacquard fabric, clearly presenting the theoretical aspects of this innovation, i.e. the design concepts, principles and methods of digital jacquard textile design.

Chapter 4, 'Structural digital design of jacquard textiles', sets out to identify the key design issues, constraints and solutions found over the course of digital jacquard textile design, using the new design concept of the layered-combination design mode in which the structural design methods available and their related colour expression are studied. The chapter describes the practical design of fabric structure, involving the design

methods of gamut weaves and weave-database, and compound structures as well as full-colour compound structures.

Chapter 5, 'Colourless and colourful digital design of jacquard textiles', reviews practical research in colour design and, in particular, colour mixture theory and the phenomenon of woven structure. It includes two integrative studies into design practices in both the colourless design mode and the colourful design mode.

Chapter 6, 'Digital design of novel simulative effects in jacquard textiles', introduces design creations made in simulative digital jacquard fabric under the layered-combination design mode, as well as original design illustrations created in both black-and-white and colourful simulative digital jacquard fabrics.

Chapter 7, 'Digital design of shot-effect and double-face effect jacquard textiles', introduces design creations in innovative digital jacquard fabric under the layered-combination design mode, and original design illustrations in both figured shot-effect digital jacquard fabric and figured double-face digital jacquard fabric.

Chapter 8, 'Applications of digitally designed jacquard textiles', presents case studies of existing and possible products for which digitally designed jacquard textiles can be applied. In conclusion, Chapter 9 summarises the investigative work involved in the preparation for this project, including a summary of design creations and the major findings obtained. Outstanding problems and recommendations for further research work are also presented.

Appendices 1 to 3 present gamut weaves and weave-databases for 12-, 16- and 24-thread satin, fabric technical specifications with lower and higher warp density, and examples of various effects of digital jacquard textile designs respectively.

1.4 References

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The development of jacquard fabrics and textile design methods

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Abstract: This chapter introduces the history of jacquard, including a discussion of the features of jacquard textiles and the evolution of jacquard fabric design. Chinese brocade and Western tapestry, two representative traditional (pre-digitisation) design methods for figured colourful woven fabrics, are presented and analysed in depth, in order to illustrate the difference in design principles and methods between the design of traditional jacquard fabric and more contemporary digital jacquard fabric.

Key words: digital, jacquard, woven, fabric, layered-combination, Chinese brocade, tapestry.

2.1 Introduction

This chapter introduces the development of jacquard technology and the evolution of jacquard fabric design. This includes the background and corresponding design technologies, an introduction to the design methods used in traditional multicoloured jacquard fabric design, and the creation and development of digital technologies that are applicable to jacquard textile design. The design methods used in traditional Chinese brocade and Western tapestry are presented for comparison as a means through which the limitations of the single-plane design mode for traditional jacquard fabric are explained. It is precisely these deficiencies that laid the foundations for innovations in digital jacquard fabric design.

2.2 The development of jacquard textile technology and design

Jacquard textile has often been referred to as figured woven fabric. Jacquard textiles were initially manufactured using traditional manual technology. The original treadle loom was later renamed the ‘pattern’ or ‘draw’ loom (Zhou, 1988). However, the term jacquard textile did not come into use until the widespread application of the ‘jacquard machine’ – an automatic figuring machine invented by Joseph Jacquard in 1804 (Charlin, 2003). This machine used a set of punched cards to indicate the woven pattern

and was mechanically controlled, so reducing the manpower previously necessary for the weaving of elaborate and intricate patterns. Today, the new generation of electronic jacquard machines such as *Unival 100*, which is produced by the Swiss Staubli Company, have extended the technical limit of the jacquard machine and may have 6144 to 20 480 individual needles/yarns (Charlin, 2003). The modern electronic jacquard machine has more than 20 000 individual hooks. These technical advances have greatly extended the design and production possibilities.

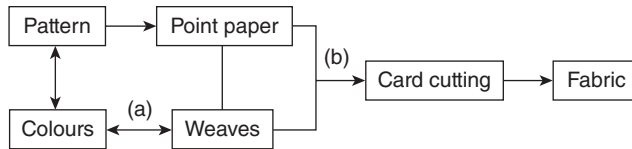
Traditional jacquard textile design consists of applied art work that combines aesthetic judgement and technology-based handicraft. In 1887, the Arts and Crafts Exhibition Society held its first art textile exhibition in London. This event was the first to provide an artistically sympathetic environment for jacquard textiles. In 1923, the Bauhaus exhibition *Art and Technology – A New Unity* was held in Weimar. A wide range of work was exhibited, from high-quality textile art to pioneering designs in art and technology for industry. These works established the concept of contemporary textile ‘design’, the influence of which endures to the present day (Cumming and Kaplan, 1991). Today, jacquard textiles play an increasingly important role in commerce and industry, due to their artistic merit and commercial potential which offer resources and inspiration for fashion and interior designers.

Jacquard textiles have been showcased in major international textile shows and exhibitions in Paris and New York, attracting buyers and designers from around the world to view the latest trends. However, along with the rapid development in creating textiles by means such as novel knitting and innovative printing, jacquard textiles manufactured by traditional design concepts and methods can no longer satisfy the needs of discerning customers. The rapid development of digital technologies in the fields of design and production are providing a powerful tool for renewing this category of ancient and beautiful textiles.

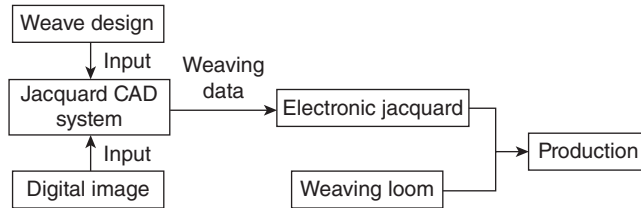
Jacquard textiles have been designed in much the same way for thousands of years, using the so-called single-plane design mode. The designs were produced by conventional concepts and methods that required a great deal of manual work. The traditional design and production process of jacquard textiles involve three major phases:

- pattern and colour design;
- weave and structure design;
- craft design which consists of point paper drawing and card-cutting planning.

All these demand skill and a good understanding of woven fabric structures. Figure 2.1 summarises the process of jacquard fabric design by the traditional plane mode. As it was restricted by the one-to-one corresponding



2.1 Design processes of jacquard fabric in a single plane design mode. (a) One-to-one corresponding principle between colours and weaves; (b) card cutting plan.



2.2 Workflow of digital jacquard design and production.

principle for fabric structural design, colour expression could only be achieved through a laborious and intricate process and the number of colour possibilities was limited. Where jacquard fabric was designed to simulate the colour effect of a given image, the task would be very complex and time-consuming due to the variety and intricacy of the weaves involved. Repetitious trials were often required before an optimal weaving structure capable of approximating the colour effect of the designated pattern could be obtained.

2.3 The development of digital technologies for jacquard textile design

Digital jacquard technology includes design-aid technologies, such as the jacquard CAD system, and production technology including electronic jacquard machines and new-generation weaving looms. The data for the design and production processes is processed, controlled, and transmitted by computer systems, thus providing a technological base for innovative digital design. The design and production procedures are shown in Fig. 2.2.

The jacquard textile CAD system dates from 1979 and has developed along with rapid advances in computer technology. In less than 30 years, it has evolved from a system with a small RAM (random access memory) and low speed, to one having a large RAM and a high speed. It is probable that an artificial intelligence CAD system will soon be able to perform most of the necessary design work and it is anticipated that such a system will play

an increasingly important role in guiding new design concepts for jacquard textiles.

Digital applications have become the leading technology for CAD systems. They have enabled a new range of visual experiences and have a wide range of applications across creative fields, e.g. advertising, fashion, graphics, illustrations, and textiles. Digital technologies that take advantage of the rapid developments in computing science and technology are now being created for the design and production of jacquard textiles. It is envisaged that the deployment of digital technology will establish a new set of design principles and methods for the production of unconventional digital jacquard textiles with significant aesthetic and commercial value.

The concept of digital textiles has been derived from that of printed textiles. Digital textiles were first proposed at the International Textile Machinery Association (ITMA) exhibition of 1999, which was held in Paris. The wider applications of digital technology in the design and production of textiles was already arousing interest at this time and research into the digitalising of woven textile design was undertaken with the aim of revolutionising traditional design methods. In 2004, a digital textile forum was held in Hangzhou in China, where 'The development of digital woven technology and its design creations' was one of the forum topics (Zhou and Ng, 2007d). The design of digital jacquard fabric has attracted particular interest in the area of digital textile research.

During the past 30 years, research on computer-assisted jacquard textile design has developed rapidly, along with advances in digital technology. Since the focus differed between researchers, the methodology employed also differed. However, all the research shared a common objective in attempting to revitalise the traditional jacquard design method by the deployment of digitisation technology. The foundations of digital jacquard research lie in the two traditional structural design methods of Chinese brocade structure and Western tapestry structure. A summary of the major research in digital jacquard textile design follows.

Prior to the introduction of the CAD system in 1979, jacquard fabric was manually designed. The application of the jacquard CAD system enabled an increase in design efficiency (Zhou, 2003). However, the computers used at that time had a lower specification, and the design concepts and methods were therefore still fairly traditional.

In 1996, the German company Kaiser Lutz introduced a process enabling jacquard to be woven into coloured fabric by using a scanning process that split the original colour pattern into black and white and three primary colours. Each colour element was at least the size of one weaving point. Different colours were obtained through the combination of adjacent weaving points consisting of the three primary colours as well as black and white. This stimulated increased research into the computer-assisted design

of coloured jacquard fabric using primary coloured yarns. Nevertheless, the design concept remained that of the traditional plane design mode, taken unchanged from Western tapestry. The new design method merely increased efficiency by application of the CAD system, the design effect and creative scope remaining that of traditional jacquard tapestry.

In 2001 and 2002, Li proposed a design method based on Chinese brocade structure using the jacquard CAD system. Jacquard fabric imitates art works by the use of five to eight threads of primary colours. This suggested a new design concept and method which made possible the design of richly coloured jacquard fabric using many thousands of mixed colours by the deployment of designated regular shaded weaves (Li, 2001 and 2002). The method separated a scanned pattern into five to eight threads of basic colours. Twenty-two shaded weaves for each colour were then computer-set to form a compound fabric construction giving varied colours on the fabric surface. If threads of the same colour as those chosen for the original colour separation were used, a coloured brocade was produced that would theoretically imitate the colour effect of the original pattern. However, due to the restrictions of the traditional plane design mode, the new compound structure was unstable, the covering effect among threads was difficult to control, and there were marked colour variations in the final fabric. A colour table and fabric colour samples is therefore indispensable if an accurate reproduction of the original pattern is to be obtained. This consisted of a combination of 32 shaded weaves which acted as an aid to design (Li, 2004a).

Figure 2.3 shows the partial fabric samples of a colour table for a design process consisting of the selection of primary colour threads, the production of a colour swatch with different compound weaves, and computer measurement of the colour data. Although the colour table may be used for colour matching between the original pattern and the final fabric, and is suitable for computerised processing, a large amount of preparative work is required before its application to jacquard fabric design. The colour table is only of use in the colour reproduction of a given image and a particular fabric specification. If these parameters are changed, it will be necessary to rebuild the colour table. Currently, the Zhejiang Sci-Tech University (Li, 2004b) and North Carolina University (Mathar *et al.*, 2005) are conducting research on a colour table approach to the structures of both traditional



2.3 Partial fabric samples of colour table.

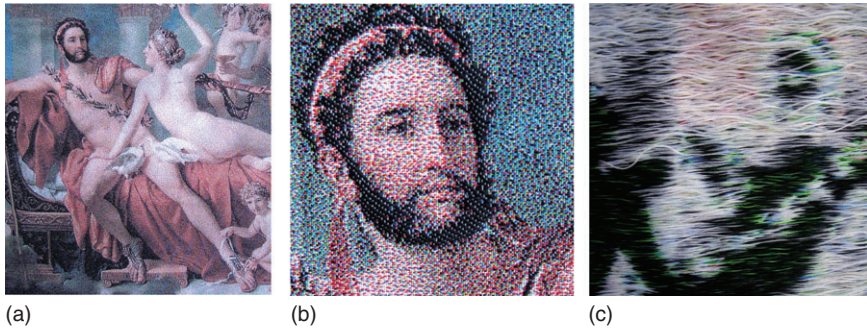
Chinese brocade and Western tapestry. It should be noted that although it is of little benefit to innovation in jacquard textile design, this approach is important in computer-programmed design for jacquard fabric in the traditional plane design mode.

In 2001, Zhou presented a design method for coloured jacquard fabric based on the merging of Chinese brocade structure and Western tapestry structure. This made use of four basic colours (red, yellow, green and blue). With the addition of black and white, two special colour systems were set up for the colour reproduction of jacquard fabric with an unrestricted structure. The research also suggested two structural design methods for the proposed colour systems. However, due to the restrictions of the traditional plane design mode, the resultant fabric structure was unsatisfactory and did not meet the theoretical requirements of the colour systems (Zhou and Gong, 2001).

In 2002, Speich presented a method of manufacturing coloured patterned textile structures in which at least four weft threads of different basic colours were inserted in a specific unvaried sequence and a consistent cell structure was formed using at least one thread (Speich, 2002). This method was based on the structural design method of Western tapestry, although the mode remained that of the traditional plane design. The intention of this research was to offer a means of combining Western tapestry design with the jacquard CAD system. However, the shortcomings of Western tapestry structural design remained and although the design efficiency was increased, the fabric structure and colour expression were still limited.

In 2002 and 2004, Zhou and Ng, inspired by digital image design, proposed a layered combination design method using digital imagery and employing the CMYK colour mode from colour separation to structure combination. This research attempted to reinvent the traditional plane design mode as a new phase in jacquard fabric design by using a layered combination method, i.e. an individual fabric structure first designed and then combined to form a compound structure. It was hypothesised that even without the production of additional colour tables, the use of compound fabric structures would enable the expression of a high level of mixed colours on a fabric surface. Although this offered a new design concept and was sufficient to create a jacquard fabric with a true-colour effect (Zhou, 2002c; Zhou and Ng, 2004), little study was done on an optimal structural design method because of the complex structural problems presented by the deployment of different regular shaded weaves in the design of compound structures. Attempts to control colour stability on the fabric surface have so far been unsuccessful.

In 2004, Speich presented a further design method relating to the patterned fabric of an image. This method has the advantage of exactly



2.4 Stipple-like effect of digital jacquard fabric. (a) and (b) Detail; (c) reversed.

reproducing an image by forming a cell with two warp and two weft threads. The cell has a defined colour which is characterised by weaves formed irregularly in both the warp and weft direction without repetition (Speich, 2004). The research presented an interesting design approach suitable for computer-programmed design. It targeted patterned fabric with a colour mixing effect similar to that of a bitmap digital image as displayed on a computer screen. This avoided the restriction of the traditional plane design mode and simulated jacquard fabric design directly from a digital image. However, the digitisation of irregular weaves caused the structure to be covered with over-long floats on the reverse side. Although the simulative effect was more satisfactory than had previously been the case, it caused new technical difficulties. The compound fabric structure failed to meet the technical requirements of mass production due to unbalanced interlacing of the coloured threads. The random digitisation of weaving points also caused a stippling effect which meant that a colour-shading effect, such as that found in prints, could not be reproduced. This effect is shown in Fig. 2.4.

The literature shows the initial research on digital textile design to be largely based on the traditional Chinese brocade and Western tapestry structures. The intention is to improve these traditional design methods and procedures by computer-aided design technology, focusing on increasing design efficiency and production by means of simulative design, i.e. the imitation of hand-made paintings through the use of primary colour yarns in the jacquard CAD system. However, due to the unpredictable expression of mixed colours and the complexity of compound fabric structures, simulative designs have so far proved unsatisfactory. Although several colour tables consisting of three to eight basic colour threads have been suggested for jacquard fabric design, the traditional plane design mode and one-to-one corresponding design principle are still employed. The problem of colour deviation in the finished fabric remains to be solved.

2.4 Design methods for traditional multi-coloured jacquard fabric

The literature on the evolution of jacquard textiles and the related design technologies has inspired the re-invention of the traditional plane design mode through digitised design and technology. Research in the field of digital jacquard is believed to have considerable potential value for design applications. The design and production of multicoloured jacquard fabric makes high technical demands, and the construction of innovative fabric structures will be necessary if a breakthrough in figured coloured jacquard fabric is to be achieved. Review of the literature shows two types of structural design methods in traditional jacquard textiles. They are brocade structure, a type of weft-figured fabric structure found in ancient Chinese figurative coloured fabric, and tapestry structure, a warp-figured fabric structure common in Western figurative coloured fabrics. These two structural design methods, which both use the single plane design mode, have endured for thousands of years. They provide the essential technical reference for innovative digital technology design.

2.4.1 Design principles and methods for Chinese brocade

Chinese brocade is a type of figured silk fabric that originated in ancient China. Multiple wefts are employed in conjunction with one series of warp threads. All the wefts float on the surface to produce the figured effect and to assist in forming the basic structure. It may therefore be described as a weft-figuring fabric with an intricate weft-backed or multi-layered structure. It is considered the highest achievement of silk fabrication in ancient China and is still well received in today's international market. Brocades with two, three or four wefts, all featuring complex weft backed fabric structure, are typical. In the study, a three weft brocade of weft-backed structure was selected as an example of the design principles and methods of traditional Chinese brocade fabric.

Design principles and methods for colour

Chinese brocade is an exquisite fabric made with coloured silk threads, producing a colourful and magnificent woven effect, and it was originally a weft-figuring fabric. Since the Sui and Tang Dynasties, weft-face brocade has held a dominant position among textiles due to advances in figuring technology and the ease of changing the colour of the weft threads. Since weft-figuring fabrics require a backed structure, the design of Chinese brocade often avoided sharp contrasts of colour to reduce the colour effect of the backing threads. Colour gradients were usually made up of similar

shades and were superimposed on one another. Thus the artistic effect of traditional Chinese silk brocade, which is complex but ordered, was achieved with the patterning of beautiful and subdued colours. Chinese brocade was also characterised by the use of the so-called ‘live-colour’ method, in which colour wefts are changed in rotation. The repeated pattern enabled a greater range of colour than could be obtained with three basic weft colours.

In a brocade structure with three wefts and one warp, the pattern effect will be mainly determined by the use of weft colours fabricated on a weft-backed structure. Thus the design principle used in Chinese brocade confirms the available colour palette before making the pattern design. The number of colours in the palette will be limited by the application of weft threads. Only seven colours can normally be used in designing a brocade fabric pattern. These consist of one warp grounding colour and six basic patterning colours of wefts arranged in single/couple colour threads. Even when the length of weft floats in the weave structure is changed, the restrictions of working by hand will only allow the maximum available for pattern design to be less than $1 + 7 \times 4$; that is, 29 colours, assuming each basic weave to have three variants. For this reason, the chintzing technique was frequently used in the design of multicoloured Chinese brocade to increase colour expression on the fabric. Figure 2.5 presents a brocade fabric designed with the renowned *Tuan Hua* image. The figure was produced in three weft colours, with a pick inserted into each weft in succession. Two of the wefts were inserted continuously and the third was chintzed (a varying of four colours in each repeat of the pattern) to add variety to the design. In this colour example, one weft floats with the colour shown on the surface while the second is plain woven underneath and is therefore invisible from both the face and reverse sides. The third floats on the reverse side where it is



(a)



(b)

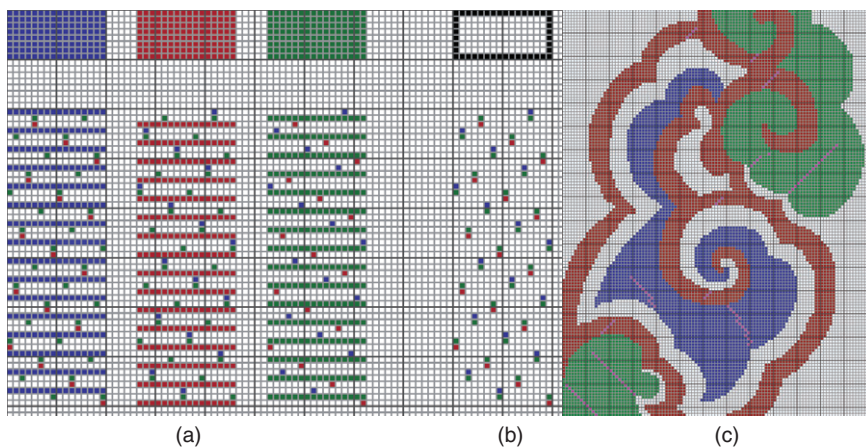
2.5 Effect of Chinese brocade with chintzing. (a) Face side; (b) reversed side.

loosely stitched. The ground colour effect is usually formed by a warp-faced satin with three wefts (Zhejiang Institute of Silk and Textiles, 1987).

Design principles and methods for structure

Structural design is important in Chinese brocade design as colour expression can be realised only by appropriate structural design. The literature deals with two categories: patterning weave and ground weave. The ground weave of Chinese brocade fabrics is normally formed by a coloured warp, woven in a regular satin weave. It features a high warp density in which one needle is connected to a harness carrying two warps. A special shedding device, called a lifting rod, is installed to raise the single warp which forms the shed and weaves the fabric. The shed of the ground weave is controlled by the lifting rods. In pattern weave design, the long floats serve as the basic element of the colour and pattern on the fabric surface. As multi-wefts are deployed in Chinese brocade, the arrangement of the wefts lays the foundation for the structural design of the fabric. The patterning weaves are produced through the interaction of hooks and lifting rods, and matching these during the design process is a difficult task.

Figure 2.6 shows a simplified weave design for brocade structure which has been condensed to three wefts. A different colour is used to indicate the float of each of the three surface wefts and the ground is left blank. The detailed weaves for each of the colours in the painted area of the point paper drawing are shown in Fig. 2.6 in the corresponding columns. The pink colour points serve as cutting points for shortening the over-long floats in



2.6 Structure design for Chinese brocade with three wefts.
(a) Patterning, (b) ground and (c) point paper drawing.

each weft. As the cutting point indicates the place where the warps do not rise in the weaving of the reverse face to avoid conflict between the weaves of hooks and lifting rods, the cutting points on the patterning weft must locate the position of the even-numbered grids on the point paper.

It will be seen from Fig. 2.6 that one out of three wefts in each patterning weave form continuous figuring floats without any cutting points on the face of the fabric. The other two colour wefts exhibit colour floats in 1 and 15 order and 1 and 7 order, respectively, on the underside. In the ground weave, an eight-satin compound weave is designed by using three wefts in succession. As Chinese brocade is designed to be a backed structure in which the first and third colour wefts are stitched on alternate binding points in the same shed as that of the second colour weft, the first or third colour wefts (especially when they contrast strongly with the warp) are moved to the background. This prevents the solid colour ground effect achieved by the warp-face satin weave from being spoiled. The structure allows the warp-face eight-satin on the second colour weft to be shown on the face of fabric. The compound weft-face 16-sateen, which combines the first and third colour weft, is formed on the reverse side. In addition, both the first and third colour wefts may utilise the chintzing technique to enrich the colour effect of the fabric.

2.4.2 Design principles and methods for European woven tapestry

Tapestry was originally a decorative fabric constructed by warp and swivel wefts, and could be produced only manually (the technique was named *Ke Si* in ancient China) (Zhao, 1992). When weaving and patterning machines came into use for the mass production of tapestry, woven construction using a through warp and through weft became popular throughout Europe. Fabric woven in this manner displayed colour effects similar to those of hand-made tapestry and was described as 'woven tapestry structure'. Since then, woven tapestry has become a typical multicoloured woven fabric in the West and is in wide use today. It is usually a yarn-dyed product made of cotton, linen and/or woollen materials and is widely used for upholstery and clothing textiles. Between four and six coloured yarns are used in the warp direction and two to four in the weft direction to produce a rich colour expression.

Design principles and methods for colour

The colour effect of woven tapestry is formed by interlacing points of the warp and weft, and is dependent on the fabric structure and the colours of the warp and weft threads. Coloured warp yarns form the colour on the

surface of the fabric, whereas the colours of the weft threads are usually employed to adjust the colour brightness. The arrangement of the warp and weft colours in woven tapestry is therefore important in the fabric design. The typical colour arrangement for woven tapestry having four to six warps and three wefts are as follows:

- (i) In four-warp fabric, the colours are red, yellow, blue and green, while the weft colours are black, white and silver-grey (silver-grey is for stitching the weft).
- (ii) In five-warp fabric, the colours are red, yellow, blue, green, black or white and the weft colours are black, white and silver-grey (for stitching the weft).
- (iii) In six-warp fabric, the colours are red, yellow, blue, green, black and white and the weft colours are black, white and silver-grey (for stitching the weft).

Red, yellow, blue and green are the fundamental colours of multicoloured woven tapestry fabric. The fundamental and mixed colours provide the colour and figured effect on the face of a fabric, whereas black and/or white are used to adjust the brightness and saturation of the mixed woven colours. The colour palettes for selecting warp colours are set up by extending the fundamental colours to the serial colours in which each fundamental is taken as the centre. This enables textile designers to handle thousands of colour-mixture effects. Black and white are the basic colours of the weft group and can be extended to include dark and light colours. Neutral colours are the best choice for stitching wefts due to their minimal influence on the face-colour effect.

Three colouring methods: single warp colouring, double-warp mixed colouring and three-warp mixed colouring, can be used in designing woven fabrics with mixed colours when the warp group consists of four to six colours. In tabby weave, for example, the appropriate warp colour principle and the number of warp colours are specified as follows, where N represents the number of warp groups (Zhou and Ng, 2006c):

$$\text{Colouring method of single colour: } C_N^1 = N \quad [2.1]$$

$$\text{Colouring method of double-colour: } C_N^2 = N(N-1)/(1 \times 2) \quad [2.2]$$

$$\text{Colour development method of three-colour: } C_N^3 = N(N-1)(N-2)/(1 \times 2 \times 3) \quad [2.3]$$

When three wefts are employed in the weft direction, the additional warp may interlace with the stitching weft. Where the warp colour on the stitching weft does not consist of more than two colours, the calculation of Eq. 2.1 should be multiplied with $C_{N-1}^1 + C_{N-1}^2$ the result of Eq. 2.2 multiplied with $C_{N-2}^1 + C_{N-2}^2$; and the result of Eq. 2.3 multiplied by $C_{N-3}^1 + C_{N-3}^2$ or C_{N-3}^1

($N = 4$). When considering the application of the warp colour principle and the colour number on two weft colours of black and white respectively, the colouring number on the fabric surface calculated above is re-duplicated. Taking four-colour warps and three-group wefts as an example, the mixed colour number on the fabric surface under the same weave structure will be as follows:

$$\begin{aligned}
 & [C_N^1 \times (C_{N-1}^1 + C_{N-1}^2) + C_N^2 \times (C_{N-2}^1 + C_{N-2}^2) + C_N^3 \times C_{N-3}^1] \times 2 \\
 & = [4 \times (3 + 3) + 6 \times (2 + 1) + 4 \times 1] \times 2 \\
 & = (24 + 18 + 4) \times 2 = (\text{colours})
 \end{aligned} \tag{2.4}$$

Consequently, a tapestry with four-colour warps and three-group wefts will have 92 varieties of mixed colours, formed by changing the combination of warp colours within the same weave structure. When the fabric construction is changed to five or six-colour warps, the corresponding results will be 280 colours and 720 colours, respectively. However, due to the limitations of manual working and the complexity of the structural design, it is impractical for the available number of colours to exceed 100. Even where CAD systems are used, if the plane design mode is retained, the colour expression both theoretically and in practice, will fall short of realising the ideal effect (Zhou and Ng, 2006c).

Design principles and methods for structure

Manually created tapestry was simple in structure. Only tabby and simple twill were used in conjunction with several swivel wefts to produce multi-colour fabrics. Woven tapestry constructed by through warp and through weft continued to use simple weaves but added further groups of threads in the warp and weft directions. By combining certain basic weaves, a richer colour effect was obtained in woven tapestry due to the colour mixture of warp ends and weft picks. Woven tapestry is a complex multi-warp and multi-weft fabric structure. Figure 2.7 illustrates such a tapestry constructed with six warps and three wefts. The diversity of the patterns is obtained by figuring with colour warps and wefts. The warps are comparatively fine and therefore do not completely cover the surface picks, thus making it possible for the weft to be visible. The figuring wefts are quite coarse and are usually in contrasting colours – one very dark (normally black) and another very light (normally white). As each weft is visible, it is capable of influencing the colour of the warp that rests upon it. Thus the same warp colour area will show variation due to the different coloured wefts running underneath it.

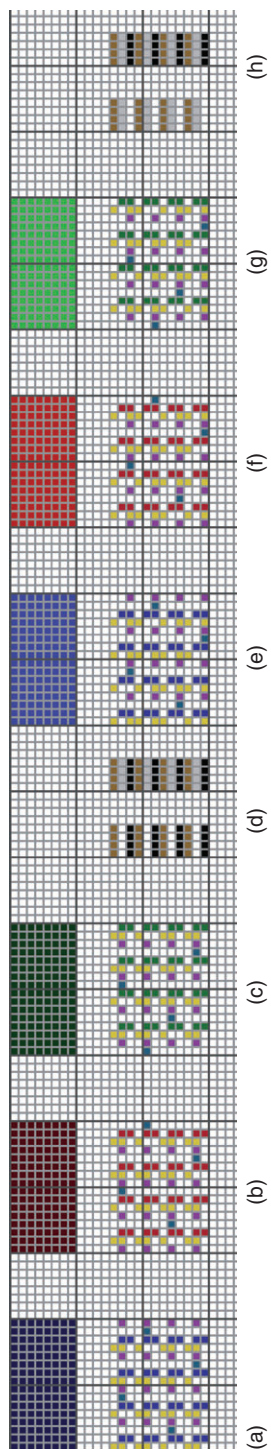
The example of a four-colour warp structure illustrated in Fig. 2.8 shows that a blue warp operating on the background of a black weft (see (a)) causes the hue of that part of the design to differ considerably from that of



2.7 Effect of Western woven tapestry with chintzed warp. (a) Face side; (b) reversed side.

another area where the same blue warp is backed by a white weft (see (d)). By using the above method, in which both wefts form an effect in conjunction with a single warp, eight distinct colour areas with four figuring warps and two contrasting wefts may be produced. It is also possible to produce other areas in which each weft figures on the face independently, as shown in Fig. 2.8. As the weft is much coarser than the warp, it covers the surface completely, causing no noticeable colour difference. The figuring threads are closely bound by the warp and weft stitching elements, so helping to achieve a distinctive ribbed, hard-wearing surface.

In each weave from (a) to (c) and (e) to (g) in Fig. 2.8, the surface colouring warp floats over both colouring picks and under the stitching pick, thus making a continuous two up and one down interlacing. One of the remaining colour warps acts as wadding and separates the wefts into face and back layers in a continuous one up and two down sequence. The third colour warp floats on the back and is loosely stitched into the body of the fabric in a satinette order. The stitches are also raised on each stitching pick, giving the characteristically ribbed appearance of this class of structure. The arrangement of the weft insertion order is shown in Fig. 2.8(d) and (h) and corresponds with the face colour wefts. It should be noted that all the weaves (a) to (c) and (e) to (g) are structurally similar and the differences between them are entirely due to changes of colour. As the basic weaves shown in Fig. 2.8 are the same, a complex structure which enhances the colour expression can be produced by changing their position. This flexible method of structural design may be regarded as the key factor in woven



2.8 Weave design illustration for woven tapestry (spread effect). (a) Dark blue; (b) dark red; (c) dark green; (d) face wefts and insert order; (e) light blue; (f) light red; (g) light green; (h) face wefts and insert order.

tapestry design as it enables multicoloured effects with a limited number of warps and wefts in a simple basic weave.

The two traditional structural design methods illustrated (Chinese brocade and European tapestry) indicate that, in principal, the colour effect of jacquard fabric is determined by the fabric construction and that design innovation is likely to be achieved through changes in fabric structure. If the fabric construction is stable, any type of coloured threads can be used for jacquard fabric design. However, an unstable fabric construction will give rise to uncertainty as to the final colour effect of the fabric. For this reason, the re-invention of jacquard fabric design through the use of digitisation technology requires a paradigm shift in the design of fabric structure. Compound fabric structure meets the technical requirements that enable jacquard fabrics to be manufactured on an industrial scale.

2.5 Conclusion

High-quality textiles such as jacquard are valued in commercial applications. However, the design of jacquard fabric by the traditional plane design mode using a one-to-one corresponding structural design method is not capable of producing the full-colour jacquard textiles required by the contemporary market. Chinese brocade and Western woven tapestry are the forerunners of complex multicoloured and patterned jacquard fabric. They offer a perfect marriage of structural design and technology on which all subsequent design innovations in jacquard fabric have been based.

Although digital technologies for jacquard textile design and production have been developed rapidly and are now widely used, the traditional plane design mode for jacquard fabric has remained relatively unchanged. While applications of the jacquard CAD system and other digital production devices have increased design efficiency, they have not contributed to innovation in jacquard textile design. The purpose of this study is the exploration of design innovations in fabric structure, and the layered-combination design mode proposed in this book is based on digital design concepts and principles. Using the layered-combination design mode, traditional jacquard textile fabric structures may be produced through digital processing. It is anticipated that this will have significant implications for the design and production of innovative digital jacquard textiles.

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Principles and methods of digital jacquard textile design

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Abstract: This chapter lays the theoretical foundation for using digital technologies to design jacquard fabric, presenting the theoretical aspects of this innovation, i.e. the design concepts, principles and methods of digital jacquard textile design.

Key words: digital, jacquard, woven, fabric, layered-combination design.

3.1 Introduction

This chapter discusses the fundamentals of research into the use of digital technology in the field of jacquard textiles. New design concepts, principles and methods relevant to digitisation in the structure of jacquard textiles are introduced. This theoretical foundation serves as a basic guide to future design research and concepts. The digital design innovations described in this book are inspired by the principles and methods of digital imagery and are known as the layered-combination design mode. This mode is divided into two categories in terms of applied digital colour theory: colourless and colourful design. The terms refer to not only the colour effect of jacquard fabrics, but also to the design processes originally introduced from the principles and methods of digital imaging. The layered-combination design method combines several colourless single-layer structures of gamut weaves to form a digitised compound structure. Jacquard fabrics constructed by this method have a print-like effect that displays high quality colour on the fabric face.

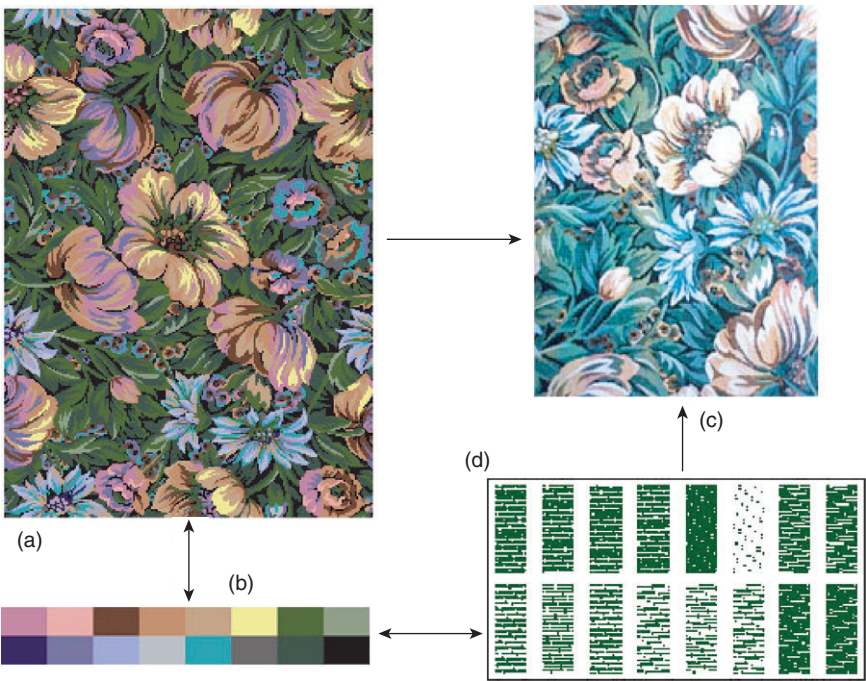
3.2 Limitations of traditional jacquard textile design

Jacquard fabrics can be divided into four categories of weaving structure: single-layer, backed structure (weft-backed, warp-backed), double-layer and multi-layer. The pattern and colour is initially designed freehand and the structural design is a technical means of imitating the effects of the original drawing (Fig. 3.1).

Although the modern jacquard CAD system improves the efficiency of structural design, the system *per se* was intended only as assistance in



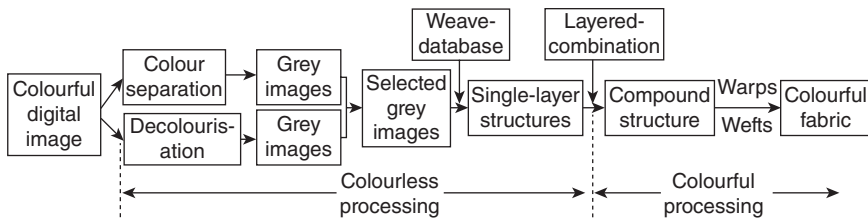
3.1 Design processes of traditional jacquard.



3.2 Single-plane design mode of traditional jacquard textile.
(a) Pattern; (b) 16 colours; (c) real fabric; (d) 16 complex weaves.

structural design (Li, 2000). The design process continued to rely on manual work, which did not lead to further innovations in design concepts and has not therefore been advanced by digital technology. Figure 3.2 summarises the design principles and methods of traditional jacquard textile design. The design of complex woven fabric structures and their appearance are illustrated below. The traditional plane design mode may be summarised as follows:

1. The pattern of a given image is hand drawn in 16 colours.
2. Based on the one-to-one corresponding design principle and the 16 available colours, 16 complex weaves are designed by combining simple weaves in a single weave design mode.
3. The fabric structure is formed through the replacement of the 16 colours by 16 corresponding complex weaves. The finished fabric will display a mix of the 16 colours and weaves.



3.3 Innovative layered-combination design processes for digital jacquard.

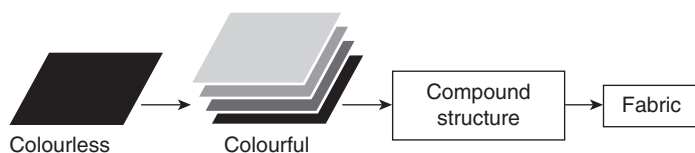
4. The fabric thus produced shows a pattern and colour effect which reproduces that of the hand drawing to the extent allowed by the colours and weaves.

Figure 3.2 illustrates jacquard textile designed in the traditional plane design mode. Because free-hand work is necessary in designing both the pattern and the weave, the process is time-consuming and complex. It requires the weaver to be experienced in designing woven structures, drawing free-hand patterns and weaving jacquard textiles. Due to the limited colour expression, traditional jacquard fabrics are designed to imitate the effect of hand painting by mechanical means and therefore this does not lead to innovation in the design process.

3.3 Digital innovation in jacquard textile design

Digitisation technology has provided a basis for innovative jacquard design by replacing the constraints of hand-working with computer technology that links design and production. As the theory of this computer technology has its origins in the principles of figured information control (James, 2006) and is based on the digital weave design method for woven structures, digitised images may be translated directly into woven structures by the layered-combination design mode proposed in this book. This design concept and method has removed the need for hand drawing and its constraints, so allowing a greater degree of innovation in jacquard design. Figure 3.3 summarises the innovative design processes.

In terms of digital image colour modes and their corresponding design methods, the study of digital jacquard design may be divided into two design parts: colourless and colourful. These terms refer not just to the subsequent colour effect of the fabrics, but also to the mode by which the fabric is designed and created. The design of colourless digital jacquard is based on the digital colourless mode (achromatic theory) and the single-layer woven structure. By using the layered-combination design method and shaded gamut weaves, several colourless single-layer structures may be combined



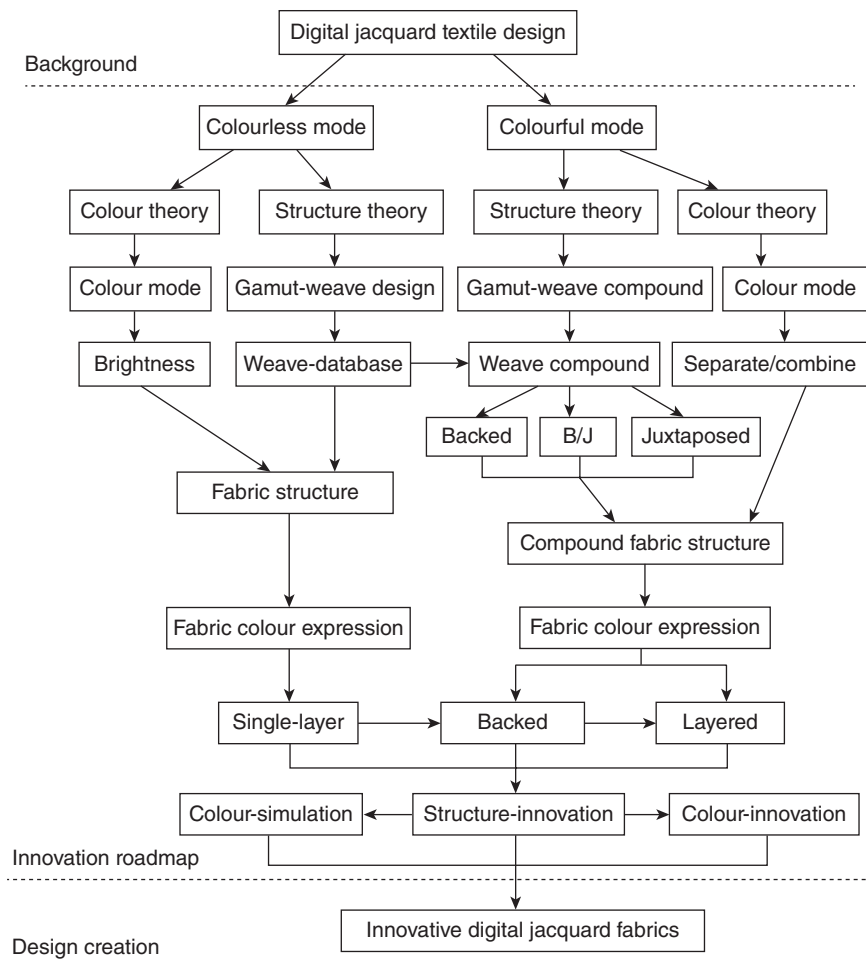
3.4 Layered-combination design mode for digital jacquard textile.

to form a compound colourful structure that enables a high quality of colour expression on the fabric surface. Digital jacquard fabric with novel digital colour effects can also be created. The core technologies lie in the two aspects of colour design and structural design. The computer image serves as the template for the structural design of jacquard fabric and does not represent the final colour effect of the fabric, which depends upon the use of coloured warps and wefts.

Figure 3.4 shows the basic design concept of the layered-combination design mode proposed in this book. In brief, colourless digital jacquard textile design is processed by merging digital colourless mode (achromatic colour) and a single-layer structure. By employing digital colour theory and the layered-combination design method, a colourful digital jacquard textile design can be produced. Fabrics produced in this way have a compound structure formed by the combination of several colourless single-layer structures. Each single-layer structure in the compound structure serves as an individual colour path for the different basic colours that contribute to the overall mix. By changing the length of floating threads in the compound structure, the mixed colours produced on the face of the fabric present a multicoloured pattern effect.

3.3.1 The research framework for digital jacquard textile design

Figure 3.5 maps the research route and the relevant key technical design innovation points by which both the theoretical and practical research were guided. The theoretical research included design concepts, principles and methods. It focused on the structural design and colour expression in the colourless and colourful design modes. A detailed working plan and a research plan for creative jacquard design are presented. The design and combination of the gamut weaves is the key technical point in the layered-combination design mode, which merges colourless and colourful digital design. A fabric structure formed by the layered-combination mode may be divided into three categories: single-layer structure, backed structure and layered structure.



3.5 Detailed research framework of digital jacquard textile design.

The *single-layer structure* is based on the interlacing of one warp and one weft. Any gamut weave may be directly applied to the design by using a colourless digital image. Although the structure is simple, the relation between the fabric structure/texture and the fabric effect may vary greatly. By changing the design method of the gamut weaves, single-layer colourless digital jacquard fabric can be produced that displays a novel grey-shaded effect. Thus the design of colourless digital jacquard fabric may be regarded as a design innovation in the digitisation of woven construction directly based on digital grey images. Indeed, any grey mode digital image can be transformed into jacquard fabric.

A *backed structure* is a compound structure that is produced by the combination of single-layer structures designed by gamut weaves. It can be divided into three types: full-backed, partial-backed and non-backed. In a full-backed structure, the backing threads are fully covered by the face threads after combination. In a non-backed structure, the colours of all the interwoven threads are visible on the face of the fabric. A partial-backed structure has an incomplete backed effect due to the different status of the thread floats, some backing threads being visible on the face side. The non-backed structure may be applied to simulative digital jacquard design, whereas full-backed and partial-backed structural design methods are more suitable for innovative design.

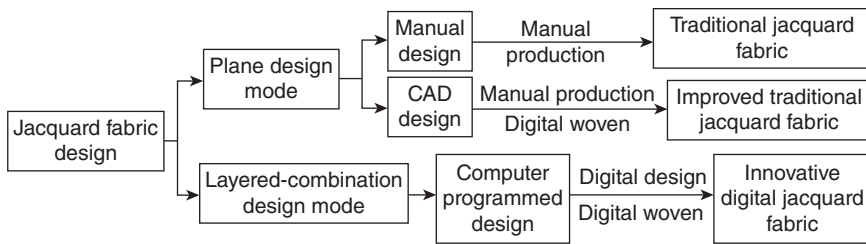
Layered structures can be generated only under the layered-combination design mode. The single-layer and compound structures are distinct and individual fabric structures. Combining two fabric structures with the aid of a stitching weave produces a compound layered structure with varied fabric effects. Layered fabric structures may be stitched from the upper to the lower layer or vice versa, and offer a convenient method of designing various patterns on both the face and the reverse side of a digital jacquard fabric.

3.3.2 Innovative digital jacquard fabric design

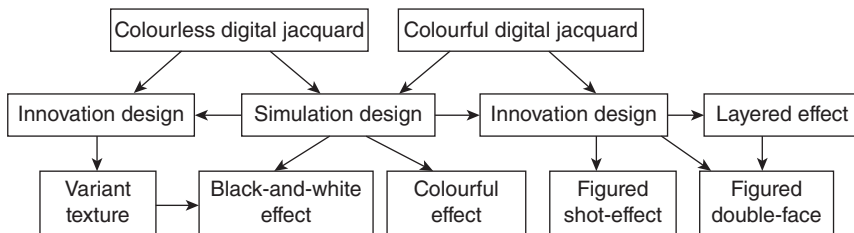
Innovation in jacquard textiles is based on the application of textile materials and their corresponding finishing techniques and/or fabric structure. In the case of digitised technology, this lies in the design of the fabric structure, by which innovation in colour and pattern effects on the fabric surface are achieved. It is also a crucial factor in distinguishing jacquard fabric from the fabrics produced by other means, e.g. dyeing, printing, knitting and embroidering.

The plane design mode is the fundamental design method for traditional jacquard fabric design, and the application of the jacquard CAD system has improved design efficiency but offers little progress in innovative design. The digital layered-combination design mode is based on the application of digitised technology through the merging of digital image design and digital colour theory. If the principles and methods of fabric structural design under the layered-combination mode are maintained, computer programmed design can be used effectively. Under these conditions, the computer replaces the manual component of the design work. Figure 3.6 summarises the relationship between design modes and creation, and illustrates the significance of the layered-combination design mode proposed in this book.

The foundations of creative digital jacquard fabric design lie in the changes in design mode and fabric structure. These propositions provide a



3.6 Relationships between design modes and design creations.



3.7 System of innovative digital jacquard fabric design.

crucial technical bridge between theoretical research, practical research and creative design. Innovative design in jacquard fabrics requires the application of digitisation technology to new fabric structures and mixed colour effects. Various effects in creative design that are made possible by this new relationship between fabric structure and colour innovation are summarised in Fig. 3.7. Innovative designs may be broadly divided into two types: simulative effect and innovative effect. However, due to the difference in colour mixture theories, simulative digital jacquard fabric offers a relatively crude simulation of the original digital image. Innovation in the design of digital jacquard fabric takes the structure of woven fabric as its foundation and may be realised either by innovation in structural design or by variations in simulative design.

3.4 Design principles and methods for colourless and colourful digital jacquard textile design

The theory of colourless digital jacquard design is based on the grey-scale mode of digital colour and the single-layer woven structure. Using the layer-combination design method, several colourless single-layer structures are combined to form a compound structure. This enables the expression of a multicoloured effect with millions of mixed colours, producing a picturesque and print-like effect with smooth colour shading.

Table 3.1 Conversion between bit lengths and grey-scales of a grey image

Bit lengths	Grey-scales
1-bit	2
2-bit	4
4-bit	16
6-bit	64
8-bit	256

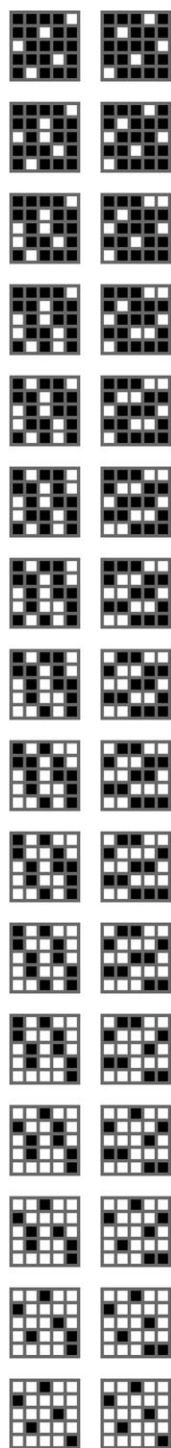
3.4.1 Design principles and methods for colourless digital jacquard fabric designs

Principles of colourless digital jacquard fabric design

According to the principles of colour design, achromatic colour consists of black, white and a series of neutral greys. In the digital colour principle, any colourless image may be rendered in, and processed by, corresponding greys without the need for any colour information such as hue saturation. White displays under the maximum brightness value and black under the minimum brightness value. Any colour image may also be converted to its achromatic version in which the greys are controlled by bit lengths. Table 3.1 shows the relationship between the bit lengths of grey image and grey-scale. An eight-bit length and 256-scale greyness will be sufficient for the expression of any image in which the grey-scale values are between 0 and 255.

A single-layer fabric structure shares certain commonalities with a grey image in terms of the processing approach: i.e. a single-layer structure designed with a shaded weave can express jacquard fabric in a similar manner to that of the grey-scale of a grey image. For example, in fabric design, a five-thread satin is generally applied with five-thread weft faced sateen and five-thread warp faced satin, respectively. Thus, if five-thread satin is designed in a series of weaves, the nature of its structural variation will be as shown in Fig. 3.8. This method could be defined as digital gamut weave design.

The gamut weaves of five-thread satin designed by the two design approaches illustrated in Fig. 3.8 produce the same results in a computer-processed grey image. The design approaches for gamut weaves may vary, but the number of weaves remains unchanged. This provides the reference for building a weave-database for colourless digital jacquard design and also fulfils the requirement of intelligent matching between the grey-scales of the digital image and the database weaves. To meet the technical requirements of single-layer jacquard fabric, the applicable weave repeats should



3.8 Digital gamut weave of five-thread satin.

Table 3.2 Data of grey-scales under different weave repeats

Weave repeat	Grey-scales ($M - R$)	Grey-scales $M - (1/2)R$	Grey-scales $M - (1/4)R$	Grey-scales ($M - 1$)
5 × 5	4	–	–	<u>16</u>
8 × 8	7	13	25	<u>49</u>
10 × 10	9	17	–	<u>81</u>
12 × 12	11	21	<u>41</u>	<u>121</u>
16 × 16	15	<u>29</u>	<u>57</u>	<u>225</u>
20 × 20	19	<u>37</u>	<u>73</u>	<u>361</u>
24 × 24	23	<u>45</u>	<u>89</u>	<u>529</u>
32 × 32	31	<u>61</u>	<u>121</u>	<u>961</u>
40 × 40	39	<u>77</u>	<u>153</u>	<u>1521</u>

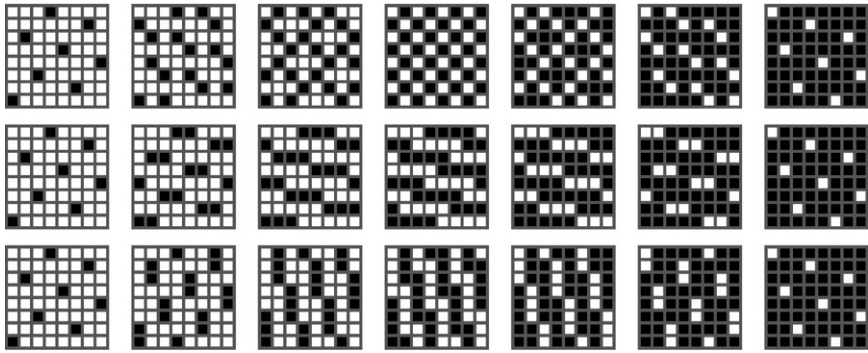
Note: M represents the added/reduced value of weaving points, R represents the weave repeat.

be in a range between 5 and 40. However, in practice, weaves require the number to be a sub-multiple of hooks for the weave repeat (Zhou, 2002b). The effective weave repeats between 5 and 40 are 5, 8, 10, 12, 16, 20, 24, 32 and 40.

Table 3.2 shows the data of gamut weaves that can be established under various weave repetitions. In processing below scale-256 greyness, the number of gamut weaves can be determined under each weave repeat. This aids structural design. The data are underlined in Table 3.2, where R represents the number of weave repeats and M represents the increased value of a weaving point among the weaves. The method of calculating the grey-scale is as follows: when $M = R$, the formula is $(R - 1)$; when $M = (1/2)R$, the formula is $2(R - 1) - 1$; when $M = (1/4)R$, the formula is $2[2(R - 1) - 1] - 1$; and when $M = 1$, the formula is $R(R - 2) + 1$. This method applies to any digital weave-database established for regular primary satins and twills. When $M = 1$, the digital weave-database will involve whole gamut weaves with all the variations of the primary weave.

Design methods for colourless digital jacquard fabrics

Using computer grey-image processing, a digital image can be converted to a grey image. As shown in Fig. 3.3, colourful digital images may be acquired through camera recording, scanning, format conversion or other digital means, and processed under various colour modes. The 256-scale grey images are formed by image processing, modification and adjustment. As there is no colour expression, the level of contrast in the grey scale must be enhanced to ensure that the brightest point of the grey scale has a value of

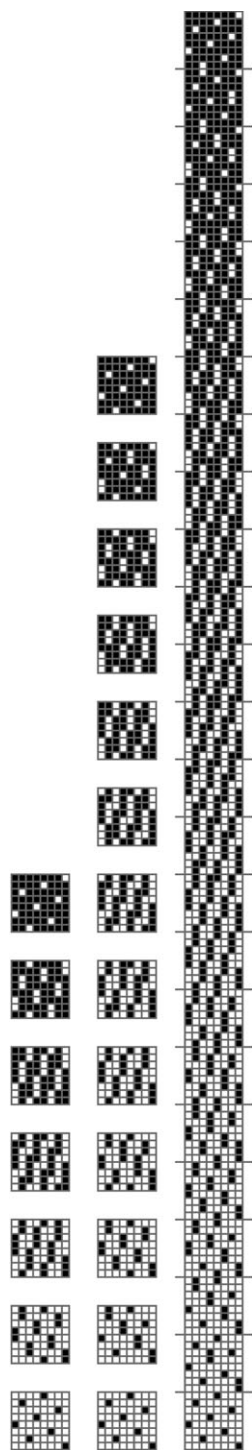


3.9 Three directions in the transition of shaded weaves.

255, while the value of the darkest is zero. The brightness of the level-256 grey scale is at Grade 1, that of level-128 is at Grade 2, and that of level-64 is at Grade 4, etc. The grey scale-image differs from traditional jacquard computer-aided design in requiring no modification at the margins which have to be edited by hand in the traditional method. In traditional structural design, where the weave design imitates the colour effect of hand painting, it is necessary to establish a digital weave-database to meet the structural design requirements for digital images with different grey-scales. However, the frequent intersection of details of the grey-scale in the digital image allows the digitised structure to remain unaffected.

The weave-database of colourless digital jacquard is formed by means of shaded weaves. Any primary weave with different weave repeats may have its own weave-database with whole gamut weaves. If the repeat of primary weaves is the same, the number of gamut weaves in the weave-databases will be identical. Under the design principle of shaded weaves, the gradual transition from warp/weft faced weave to weft/warp faced weave proceeds in three directions based on primary satin or twill: diagonal transition, lateral transition and longitudinal transition (see Fig. 3.9). Owing to the lack of balanced interlacing in its woven structure, the diagonal transition does not have a wide application. Lateral transition is applied in products where the warp density is less than the weft density. Longitudinal transition is applied to designs in which the warp density is greater than the weft density.

The increase of interlacing points in the transition of shaded weaves also plays an important role and influences the number of weaves in the database. The routine procedures for increasing interlacing points include: $M = R$, $M = (1/2)R$, $M = (1/4)R$, and $M = 1$. Figure 3.10 shows that the weave-databases of 8-thread satin are established by increasing the interlacing points under $M = 8$, $M = 4$ and $M = 2$ respectively (from top to bottom). Therefore, the weave-database of colourless digital jacquard is defined by



3.10 Methods of increasing interlacing points in the transition of shaded weaves.

M , adding value to interlacing points in the shaded weave. When M is defined as the weave repeat, the number of weaves in the database will be at the minimum value. When M is 1, the number of weaves is at the maximum value, indicating gamut weaves of the primary weave. The greater the number of weave repetitions, the more weaves may be devised for a weave-database.

Taking into consideration the principle and method of design for gamut weaves, it is apparent that a digital weave-database contains all the variations of a given primary weave. When coupled with the weave-database, the structural design is available to the colourless digital images in which the brightness of the grey scale serves as the basic parameter for the corresponding weaves. Depending on the different warp and weft colours, the maximum and minimum values of brightness may be distributed to weft/warp faced weaves or warp/weft faced weaves at the two extremes of the database. The medium grey scales can also find their corresponding weaves in the database according to the grading of their brightness. With the same weave repeats and under similar structural tension, the weaves in a digital database will automatically meet the requirements of structural balance. The weave-database of the different weave repeats that are selected for structural design will affect only the warp and weft densities of the target fabric. The design of colourless digital jacquard is therefore based on a well-organised digital weave-database without reference to the subject matter of the digital grey image. The larger the size of the digital grey scale image, the higher are the warp and weft densities of the fabric, so enabling the production of more elaborate effects.

3.4.2 Design principles and methods for colourful digital jacquard fabric designs

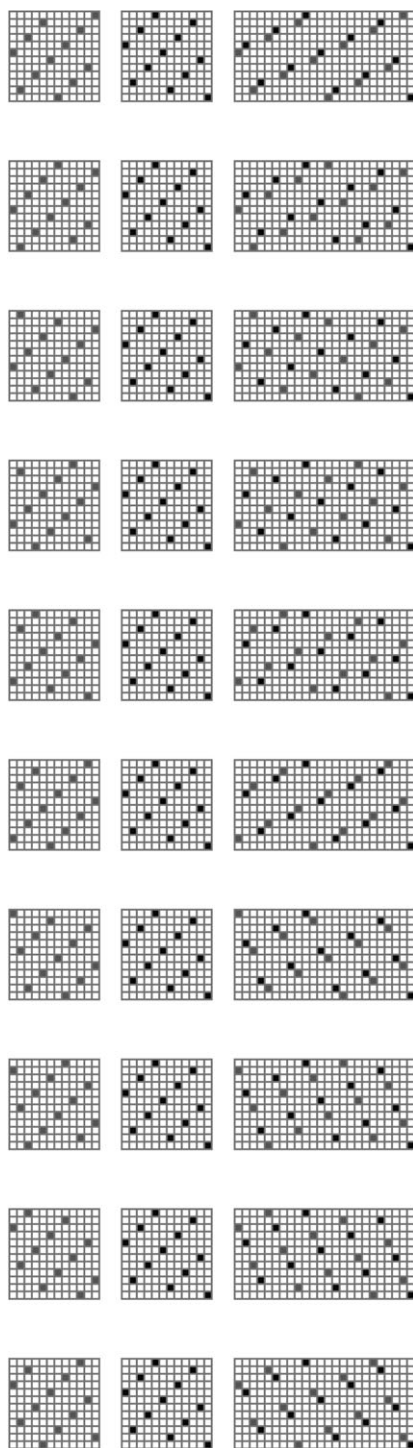
Principles of colourful digital jacquard fabric design

Primary colours are the basis for expressing the colour of an object. All colours are the result of mixing primary colours in varied proportions. Computer-processed colours work on similar principles of the mixing and separation of primary colours. The colour effect of jacquard fabric is expressed through the combination of warps and wefts in which coloured yarns serve as the primary colours in the fabric. Though differences exist between the two, they share common ground in colour mixing. This is the foundation on which innovative colourful digital jacquard design is based.

There are four differences which arise between light, pigment and the capacity of computer technology in processing primary colours. The three primary colours of light are red, green and blue, and the corresponding computer colour mode is RGB. The three primary colours of pigment are

red, yellow and blue, for which there is no corresponding computer colour mode. Neither is there a corresponding computer colour mode for the four physiological primary colours of red, yellow, blue and green. In printing, the four basic colours are cyan, magenta, yellow and black, and the corresponding colour mode of a computer printer is CMYK. The computer modes RGB and CMYK are effective references in colourful digital jacquard design, where the image colours may be reproduced by fabric construction according to the inherent characteristics of jacquard fabric. The process of reproduction both enables the simulation of the colours of any image and creates a new colour effect by means of woven construction. The colour design of colourful digital jacquard is therefore built upon a combination of digital colour theory and the colour expression of fabric construction which goes far beyond that which could be achieved manually. The colour theory of the layered combination design method may briefly be defined as follows: the colours in any digital image may be separated into monochromatic layers and de-colourised into several grey-scale images. Alternatively, they may be directly de-colourised without any colour separation. Any colourless grey-scale images could be subject to structural design according to their various degrees of brightness. The structures designed from grey images may be combined to form a compound and proportionally layered structure through which the effect of the colour mix can be extended to the fabric.

The structural design for colourful digital jacquard is based upon layer combinations and its principle may be understood as the combination of colourless digital jacquard fabrics (Zhou and Ng, 2006b). This innovative structural design removes the restrictions of the traditional plane design mode. To meet the technical requirements of balance and stability, the structural design of colourful jacquard requires a combination of identical weave types from different databases. The principle for the structural design first determines the primary weaves with which the database can be established. The weaves are then applied in the same weave-database to alternately allocated grey-scale layers. The subsequent combined structures provide a satisfactory surface effect. Figure 3.11 shows the fundamental principle of two-layer combined structural design with 12-thread sateen as the primary weave of the database. Drawings of weaves derived from the primary and compound weaves are listed from top to bottom, respectively. Based on the characteristics of 12-thread sateen, the primary weaves are 12/5 weft-faced sateen, of which 11 variations of weave are provided through displacement of the primary weave starting point. Excluding the first weave, which shows the effect of juxtaposition upon the combination, there are 10 variant weaves. Eleven digital weave-databases (including the database of primary weaves) can be set up, i.e. $R - 1$ kinds of derivation, where R refers to the number of weave repetitions. In this way, the 10 derivative weaves



3.11 Principle of structural design for 12-thread sateen of colourful digital jacquard.

of Fig. 3.11 generate 10 drawings of the effect of compound weaves in combination with the primary weave, using the combination method of 1-and-1 across weft. These 10 combination effects feature either the different weave structures or the same weave structure with a different order of wefts. They provide 10 patterns for the further addition or reduction of interlacing points. This arrangement also applies to the requirements of 1 : 1 : 1, 1 : 1 : 1 : 1, etc. However, weaves in identical weave-databases should not be arranged adjacently. From the result of the combination effect with the primary weave shown in Fig. 3.11, it could be inferred that the same result may also be achieved with the combination of gamut weaves designed on the basis of those primary weaves in the database. Combining primary weaves can also serve as a model for combining single-layer fabric structures to form a compound fabric structure.

The structural design method for colourful digital jacquard, which is built upon that of colourless digital jacquard, has the capacity to extend the range of combined colourful jacquard fabrics and to express a variety of rich colours through the availability of gamut weaves. In Table 3.3, typical grey-scales (underlined) have been selected from different repeats of weaves and a combination datum of colour development has been calculated on the two, three and four-layers, in which G represents the grey-scale, R represents the number of weave repeats and M represents the added value of the weaving point. If the same grey scale is applied to all the layers, the multi-layer colour mixture may be calculated according to G^L , in which L represents the number of layers. If the grey scales vary in any layer, the multi-layer colour mixture is calculated by multiplying all the grey-scale layers. Table 3.3 utilises the same grey scale. It is obvious that, despite use of the partial backed structure in the process of colour reproduction, the data for the colour mixing of four layers of grey images all exceed the level

Table 3.3 Relationship between colour numbers and grey-scales after combination

Weave repeat	Grey-scale $M - (1/4)R$	Grey-scale $(M - 1)$	Mixed colour 2-layer (G^2)	Mixed colour 3-layer (G^3)	Mixed colour 4-layer (G^4)
8 × 8	25	<u>49</u>	2401	117 649	5 764 801
12 × 12	41	<u>121</u>	14 641	1 771 562	214 358 881
16 × 16	<u>57</u>	225	3249	185 139	10 556 001
20 × 20	<u>73</u>	361	5329	389 017	28 398 241
24 × 24	<u>89</u>	529	7921	704 969	62 742 241
32 × 32	<u>121</u>	961	14 641	1 771 562	214 358 881
40 × 40	<u>153</u>	1521	23 409	3 581 577	547 981 281

Note: M represents added/reduced value of weaving points, R represents weave repeat.

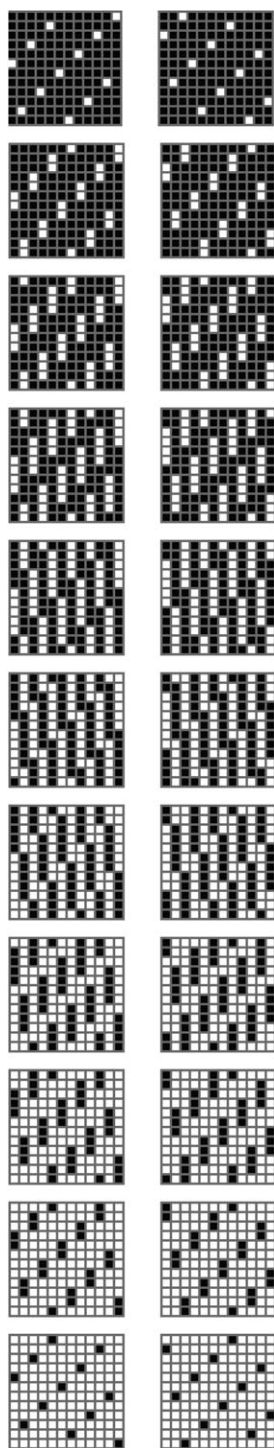
at which colour expression can be detected by the eye (Zhou and Ng, 2006a). This cannot be reproduced by traditional hand drawing. Unlike the traditional plane design mode, the number of mixed colours on the face of digital jacquard fabric is not a constant, due to the random combination effect caused by the gamut weaves. Certain mixed colours may be lost in the course of structural design. For example, in designing fabric with an eight-thread weave, 49 grey scales and a two-layer combination, the mixed colour number will vary when two single-layer fabric structures are combined, due to the change of the image used. The maximum number of mixed colours will remain 2401 and is shown in Table 3.3.

Design methods for colourful digital jacquard fabrics

The innovative principle for colourful digital jacquard fabric design displays perfectly integrated structure and colour through colour separation, layered design and recombination. By means of the design processes shown in Fig. 3.3, a digital colourless image may be obtained by four methods. RGB and CMYK colour separation are the two most fundamental and may be applied to the simulative design process. The third method is to separate the colourful image into grey-scale layers of the designated colours. However, the grey image will require modification due to the loss of information about the primary colours during the separation process. In the fourth method, the grey image is obtained directly from a desaturated colourful image that is provided with integral modelling information. Its application will therefore result in previously unattainable design effects. The grey images may be selected for structural design and combination according to the specific design requirements and characteristics of the individual grey scales.

The colour design for colourful digital jacquard provides a high degree of flexibility in the design process and allows a free choice of layered grey images for combination. The weaves in a database always remain unchanged. No matter how complex the colour design is, or how varied the layers of grey images are, the structural design does not increase in complexity. If there is no change in the colour of the weft, jacquard fabrics of various colours may be devised by modification of the levels of grey scale on the grey images (no similar values). If a digital weave-database with 12-thread sateen is taken as an example, eleven digital weave-databases could be established that are able to meet any requirement for the combined design of various grey-scale layers. Figure 3.12 shows two ($M = R$), by which alternative deployment can meet the combined design of two or four grey-scale layers, i.e. the identical digital weave-databases applied to the first and the third, or the second and the fourth layers.

As it is a fixed factor, the structural design of colourful digital jacquard has no connection with the subject matter of the digital images. Thus any



3.12 Digital weave-database of 12-thread sateen for colourful digital jacquard.

digital weave-database of any type of weave may be established independently. Intelligent design of colourful digital jacquard fabric is easily realised by using the principle of correspondence between predetermined fixed grey scales and the weaves in a database. The design effect will vary between simulative and innovative design with the change of grey-scale layers in the digital image. Since the design of colour and structure in colourful digital jacquard are comparatively independent, differing structural characteristics may contribute to innovative colour effects in the completed design. This resembles the process of modelling before introducing colouring in artistic design, and allows the creativity and personality of the designer to be expressed.

3.5 Conclusion

The design concepts, principles and methods described in this chapter replace the traditional plane design mode. Design research has merged digitisation technology with jacquard textile innovation using a layered-combination mode which integrates the basic principles of woven fabric structure, colour science and computer technology. Digital jacquard fabric designed in this way greatly increases the valid mixed colour number for a fabric surface and is unrestricted by the subject matter of digital images. Textiles with both simulative and innovative design may therefore be processed as easily as digital image printing. The results of the study suggest a new direction for research into the future design of jacquard fabric. However, as this is a relatively new field of textile research, the technical problems require further study through elaborative research and experimentation.

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Abstract: This chapter focuses on the practical research undertaken, in which key technical issues in both mixed colour theory and relevant fabric structure design under the layered-combination design mode are presented. Efficient solutions are also proposed, following good design practice and experiment.

Key words: digital, jacquard, woven, fabric, layered-combination, colour theory.

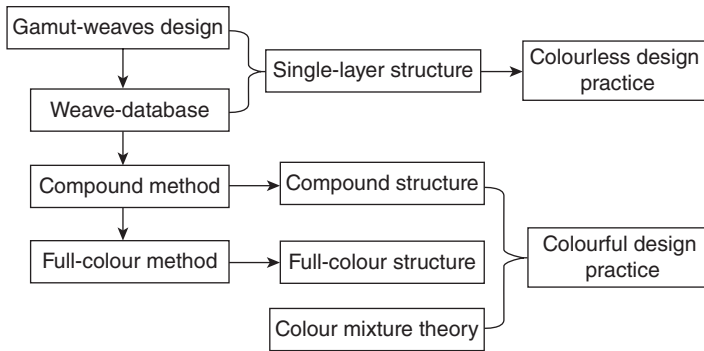
4.1 Introduction

Following the foundations of research into the design concept, principles and methods of digital jacquard textile design described in Chapter 3, this chapter sets out to identify the key design issues, constraints and solutions found over the course of digital jacquard textile design, using the new design concept of the layered-combination design mode. As discussed in Chapter 3, the key points of digital jacquard textile design lie in colour and structural design. Therefore, the relationship of structural design and its expression in colour obviously plays an important role in the creation of digital jacquard textile designs, and must be understood thoroughly. For this reason, this chapter studies the structural design methods available and their related colour expression. Any hidden problems in the course of design are identified and tackled for optimal results.

This chapter presents the practical design of fabric structure, involving the design methods of gamut weaves and weave-database, of compound structure as well as full-colour compound structure. Chapter 5 presents practical research in colour design and, in particular, colour mixture theory, and the phenomenon of woven structure. It includes two integrative studies into design practices in both the colourless design mode and the colourful design mode. Key technical points of digital jacquard textile design are shown in Fig. 4.1.

4.2 Gamut weaves and weave-database design

The results of the theoretical research proposed in Chapter 3 indicated that the layered-combination design mode enables digital jacquard fabric to

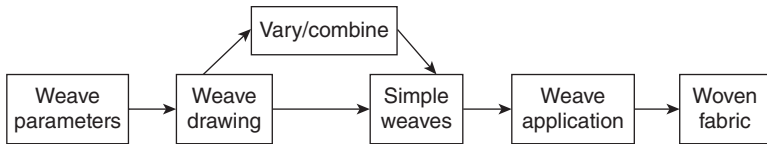


4.1 Key technical points of digital jacquard textile design.

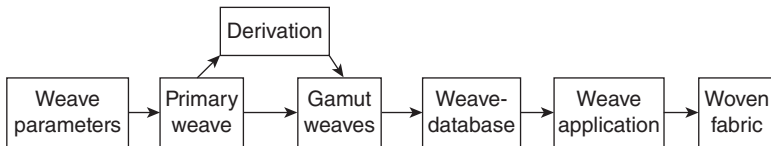
express a mega level of mixed colour effects. Thus, an appropriate method of weave and structure design should be put forward to address such a design concept. Since the traditional structural design method, with a plane design mode, is unsuitable for designing digital jacquard textile, it was essential to explore an optimal structural design method for the creation of digital jacquard fabrics for mass production.

Jacquard fabric is a kind of woven fabric with warp and weft threads interwoven with each other. This rule of interlacement is called weave. Any weave is composed of alternative warp and weft interlacing points. The number of threads required for arrangement of the warp and weft interlacing point repeats for one time is called a weave repeat, say R , and the number of threads of warp and weft in the weave repeat are represented by R_j and R_w , respectively. In general, the weaves can be divided into three categories: (i) a simple weave, which includes elementary weaves, variations of elementary weaves, and combinations of elementary weaves; (ii) a complex weave (compound weave), which includes multi-weft, multi-warp, double-layer and multi-layer weaves; and (iii) special weaves such as leno, pile and terry.

Figure 4.2 shows the traditional design approach from weave to fabric. R (weave repeat), S (step number) and other necessary parameters of the elementary weave must be confirmed first; an elementary weave can then be devised according to the principles of the weave construction. When the design is completed, the design of variation and combination weaves is conducted, based on elementary weaves. In the design of complex weaves, specific simple weaves must first be devised prior to the compound design, i.e. there has to be an arrangement and combination of simple weaves under certain prescribed proportions. Therefore, the traditional method for structural design of woven fabric always commenced with a design mode of single weave, due to the restrictions imposed by hand drawing.



4.2 Traditional design processes from weave to woven fabric.



4.3 Digital design processes from weave to woven fabric.

The digital approach to the structural design of woven fabric has caused single-weave design to be replaced by the design of gamut weaves, i.e. a series of derivative weaves based on an elementary weave featuring very similar texture characteristics. Gamut weaves are deployed to establish independent weave-databases (Fig. 4.3). In this way, the structural design of woven fabric has transformed the single-weave design mode to an integrated digital design one.

4.2.1 Design principles

The application of digital technology facilitates the upgrade of traditional principles and methods for the structural design of woven fabric. The design of woven fabric by hand-drawn patterns is being gradually replaced by computer-aided design (CAD). The design mode of woven fabric construction is also changing from single weave to gamut weaves with associated characteristics. To this end, based on the intrinsic features of weave structure, it is of great practical importance to research and establish a principle for the design of gamut weaves, as well as for methods of their application.

Nature of weave and structure digitisation design

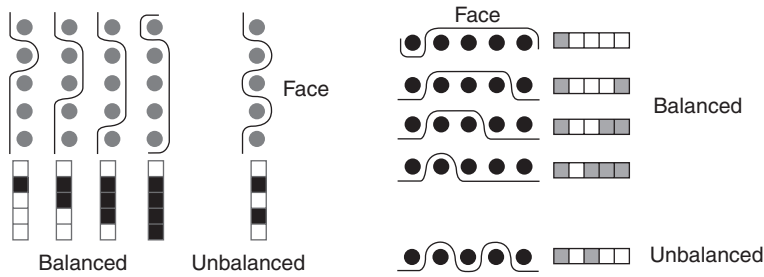
The elementary weave is the foundation for the structural design of woven fabric. Elementary weave can be defined as follows: in each weave repeat, every warp or weft has but one warp interlacing point or weft interlacing point. Notwithstanding the step number of the interlacing points, the kinds of weave that can meet the requirement for the construction of elementary weave are $2 \times (C_R \times C_{R-1}^1 \times C_{R-2}^1 \times \dots \times C_1^1)$, including both warp-face and

weft-face weaves. If the step number of the interlacing points is defined as a constant in the elementary weave, three types of elementary weave can be formed: plain weave, twill weave, and satin weave. Any weave with a practical value can be generated by variations of these three types of elementary weave. This method is also applicable to digital structural design. Based on the structural characteristics and technical requirements of woven fabric, weaves sharing common grounds and suitable for joint application can be analysed and categorised, and be further transformed into an individual gamut weave-database that meets the demand for the design and production of digital woven fabrics. However, research into the principle of digital structural design must take into account the intrinsic principles of structural design and technical requirements governing the production of woven fabric.

Balanced interlacement for woven structure

For woven fabric under warp and weft interweaving, in addition to the principle of structural design, another key factor lies in balanced interlacement because each weave is a result of the interlacement of warps and wefts, and the interlacing of straight warps and wefts, up and down, inevitably results in shrinkage of threads. If every warp or weft features the same shrinkage after interlacement, the situation can be called balanced interlacement of warp and weft. If only all the warps feature the same shrinkage after interlacement, the situation is called the balanced interlacement of warp, whereas if only every weft features the same shrinkage after interlacement, the situation is called the balanced interlacement of weft. In the traditional structural design of woven fabric, the balanced interlacement of warp and weft can be regulated at any moment during drawing point paper design. However, in digital design, the hand drawing is replaced by computer-aided design. Thus, control over the balanced interlacement of warp and weft needs to be solved in a uniform way during the process of programmed structural design. Given the high efficiency expectations of digitised production, any improper control of the balanced interlacement of warp and weft during structural design may lead to failure of operation. In fact, regardless of the quality of any fabric effect, it is not acceptable if the structural design fails to meet the technical requirement of a balanced interlacement of warp and weft.

Study of the structure of woven fabric has revealed that the balanced interlacing of warp and weft is based on certain rules, in terms of the fabric's construction. In Fig. 4.4, in order to meet the requirement of balancing the black warps in the left section, the times of interlacing with the wefts in the structure must be the same. As the times of interlacing are independent of the length of interlacing points, every change to the properties of the interlacing points is called 'one time interlacing'. Since continuous



4.4 Balanced and unbalanced interlacement of warp and weft.

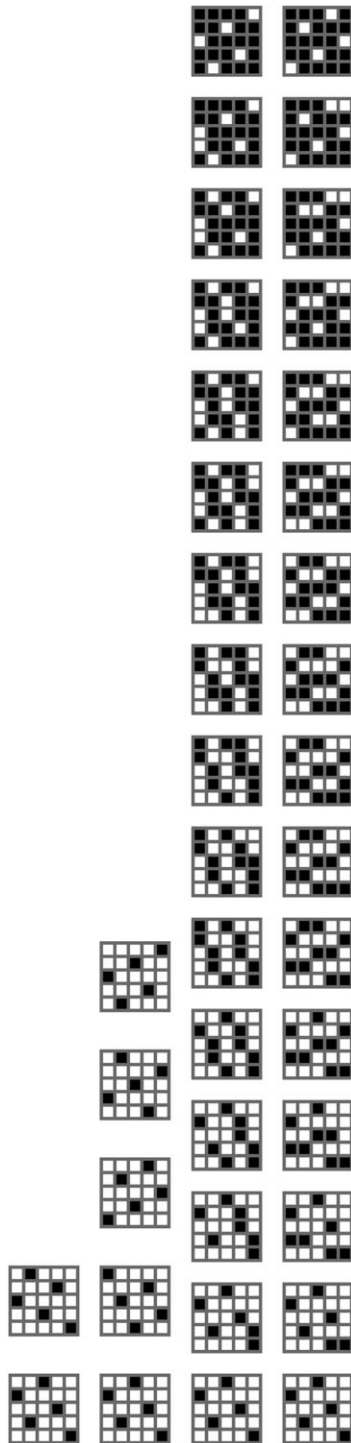
interlacing points share the same times of interlacing, the shrinkages are identical after interlacement, and the warps are of a balanced structure. This principle also applies to the weft, as shown in the right section of Fig. 4.4. In practice, since the weaving has a strict requirement on the take-up of the warp, the mode of weaving is optional, warp-wise or weft-wise, for the weave is balanced in both warp and weft. According to the design requirement, before looming and weaving, any structural design with a balanced interlacement of warp can be put into production warp-wise, whereas the weft direction must be turned into a warp one for a structural design of balanced interlacement that satisfies only the weft.

Design principles of gamut weaves and weave-databases

In terms of the design principles of a woven construction, any structural design is built upon the three elementary weaves, on which new weaves can be formed through derivation and combination. The gamut weaves now proposed also consist of a series of derivative weaves based on the three elementary weaves. Gamut weaves contain all the variable information that is suitable for the design of digital woven fabric, and feature the same characteristics of the weaves as well as the same method of application.

The three elementary weaves, the simplest of all weaves, have the basic construction characteristics of having the same warp and weft weave repeat, i.e. $R = R_j = R_w$ with only one interlacing by a warp or a weft, as well as a constant S for the step number of interlacing points in a weave. Given these characteristics, a series of derivative weaves can be devised by changing the number of interlacements, step numbers or the starting points of the three elementary weaves. Plain weave has only one variation parameter at the starting point of weave, whereas twill weave has two, i.e. the number of interlacements and the starting point. Its step number is fixed at 1, or $R - 1$. Satin weave has all three parameters.

Figure 4.5 takes a five-thread satin, for example, and shows (from top to bottom) the series of weaves generated by varying the step number of a



4.5 Design principles of gamut weaves on a five-thread satin.

five-thread weft sateen, a series of weaves generated by varying the starting point, and another series of weaves generated through the increase of interlacing points. The number of weaves generated by varying the step number is defined as M_s , and M_s can also be taken as the number of step numbers that can form satin weave. In this case, two kinds of step number, namely Step 2 and Step 3, meet the requirement for the five-thread satin. Taking one of the weaves as the foundation, a series of weaves can be formed through changing the starting points of weaves. If M_w represents the number of weaves and it is equal to weave repeat R , the number of weaves will be equal to five. Taking another weave among these five weaves as the basic weave, another series of weaves can be formed through increasing the interlacing points. The number of weaves is represented by M_p , thus $M_p = R \times (R - 2) + 1 = 16$ weaves (Zhou, 2002b). When increasing the interlacing points, only two methods can be adopted under the principle of balanced interlacement of interlacing points: warp-wise or weft-wise (Zhou and Ng, 2006b). As the positions of increasing interlacing points vary, given the requirement for continuous increase and balanced increase of the interlacing points, there are $C_R^1 \times C_{R-1}^1 \times C_{R-2}^1 \times \dots \times C_1^1$, namely $R!$ (factorial) kinds of possibilities on the variation for each direction. Thus, in total, there would be $4 \times R!$ kinds of method to increase the interlacing points of every foundation weave, with the top/bottom of the warp-wise and left/right of the weft-wise inclusive. In this case, the number of approaches for increasing the interlacing points in the five-thread satin is $4 \times R! = 4 \times 5! = 480$.

To conclude, theoretically, an elementary weave can entertain $4 \times R! \times M_s \times M_w \times M_p$ gamut weaves and $4 \times R! \times M_s \times M_w$ weave-databases, each of which has $R \times (R - 2) + 1$ weaves. Therefore, the five-thread satin is provided with 76 800 gamut weaves ($M_a = 4 \times R! \times M_s \times M_w \times M_p = 76\,800$) and the total number of weave-databases that could be established is 4800 ($Z = 4 \times R! \times M_s \times M_w = 4800$), each of which contains 16 gamut weaves [$M_p = R(R - 2) + 1 = 16$].

According to the characteristics of the three elementary weaves and the principle for the design of gamut weaves, it is apparent that plain weave features only one weave-database with both odd and even starting points inclusive. Table 4.1 shows data for the gamut weaves design of the three elementary weaves, where R is weave repeat; M_s is the number of elementary satins that feature identical weave repeat of different step numbers (see Table 4.2 for details), and M_w is the number of weaves at the derivation of weave starting point, i.e. $M_w = R$.

4.2.2 Design methods

The method for the structural design of digitally designed woven fabric differs fundamentally from the single-weave design mode, the principle

Table 4.1 Data for gamut weaves design of three elementary weaves

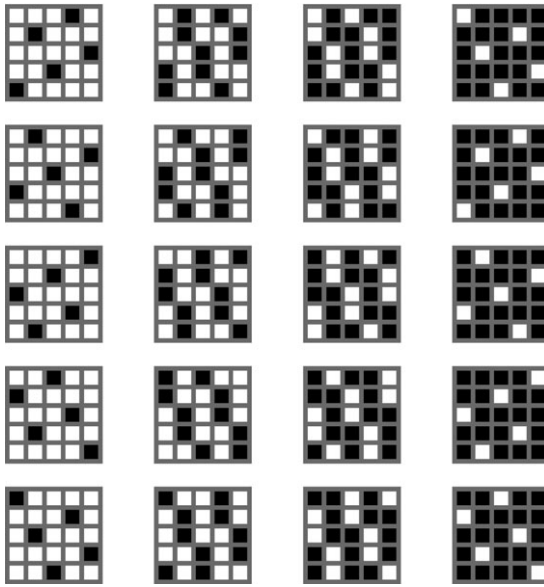
Elementary weaves	Number of weaves/weave-database M_p	Number of weave-databases Z	Number of whole weaves M_a
Plain	2	1	2
Twill	$M_p = R \times (R - 2) + 1$	$Z = 2 \times 4 \times R! \times M_w$	$M_a = 2 \times 4 \times R! \times M_w \times M_p$
Satin	$M_p = R \times (R - 2) + 1$	$Z = 4 \times R! \times M_s \times M_w$	$M_a = 4 \times R! \times M_s \times M_w \times M_p$

Table 4.2 The number of satins under different weave repeats (with different step numbers)

Weave repeat	M_s	Weave repeat	M_s	Weave repeat	M_s	Weave repeat	M_s	Weave repeat	M_s	Weave repeat	M_s
5	2	14	4	21	10	28	10	35	22	42	12
7	4	15	6	22	8	29	26	36	10	43	40
9	4	16	6	23	20	30	6	37	34	44	18
10	2	17	14	24	6	31	28	38	16	45	22
11	8	18	4	25	18	32	14	39	22	46	20
12	2	19	16	26	10	33	18	40	14	47	44
13	10	20	6	27	16	34	12	41	38	48	14

method traditionally used for structural design. Digital structural design aims to create a weave-database, and takes all weaves in a weave-database as a unit of application within which any individual weave in the weave-database can easily be replaced by any other in the same database, with no interference to the balanced interlacement of the fabric structure. The establishment and optimisation of a weave-database is key to the principle of designing gamut weaves. A weave-database can be set up in various ways; however, only one way is optimal for a specific kind of application with regard to fabric design. Figure 4.6 shows the design approach for a five-thread weft sateen, realising a balanced interlacement of both warp and weft, and providing five different displacements. This means that five different weave-databases can be established, each of them containing four weaves. Because of the balanced interlacement of warp and weft, the weaves in each weave-database can replace each other (Zhou and Ng, 2007g).

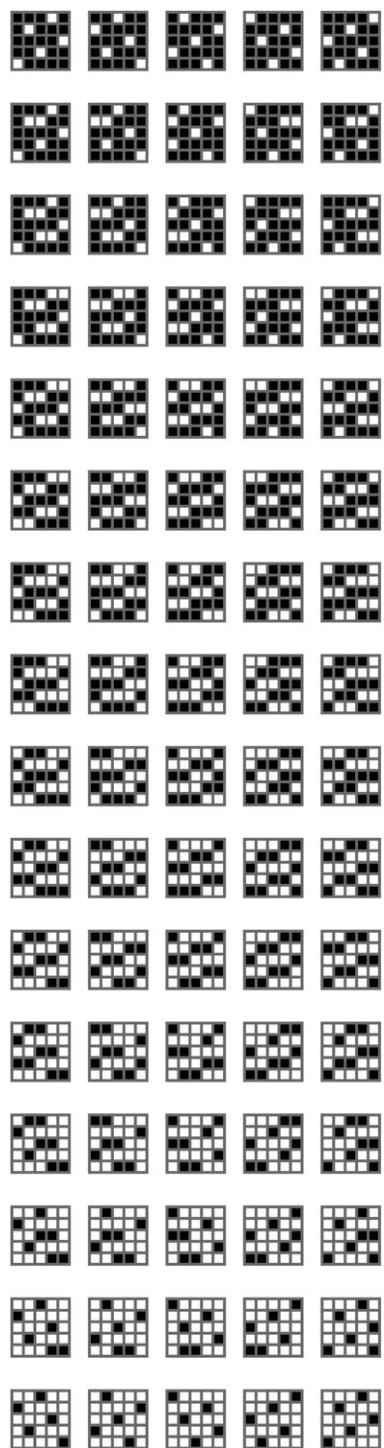
Figure 4.7 shows the design of gamut weaves for the five weave-databases of a five-thread weft sateen. These gamut weaves are based on the weaves in the weave-database shown in Fig. 4.6. The weave-databases meet the



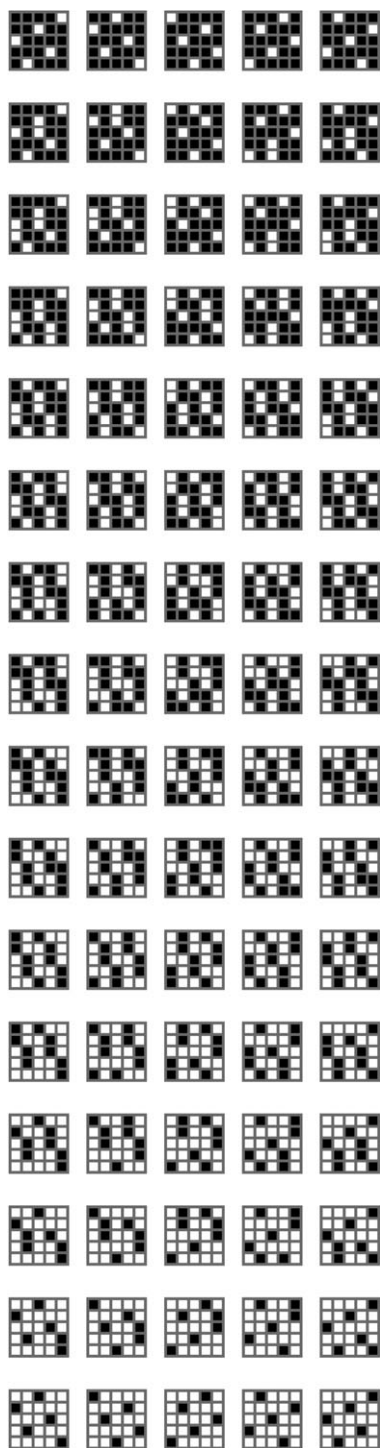
4.6 Weave-database of five-thread satin, designed under the balanced interlacement of warp and weft.

requirement of warp-wise balance of interlacing with an increase of balanced interlacing points, i.e. balanced interlacement of warp, albeit with unbalanced interlacement of weft. Thus, the application of this gamut weave-database for a fabric design can choose any weave in the same weave-database for replacement. The completed design can be immediately put into production warp-wise. This weave-database can also be applied to the design of fabric with a compound structure arranged in proportion to the warp direction, without affecting the performance of the balanced interlacement.

Figure 4.8 shows the structural designs of the five gamut weave-databases produced by the method of weft-wise reinforcement of interlacing points of a five-thread weft sateen. Although the warp direction does not meet overall balanced interlacement in the weave-database, the weft direction is able to satisfy the requirement of balanced interlacement. Since the interlacing points are added under balanced increase, this weave-database is more suitable for the design of weft-wise multiple combinations. There are three available approaches to using a weave-database directly for the design of single-layer woven fabric. First, take the weft direction of a fabric as the warp direction in looming and weaving, i.e. design the pattern laterally and weave the pattern longitudinally. Second, choose only weaves to meet the balanced interlacement of warp and weft in the weave-database for design.



4.7 Weave-database of five-thread satin designed under balanced interlacement of warp.



4.8 Weave-database of five-thread satin designed under the balanced interlacement of weft.

Third, adopt only those patterns with colours in balanced arrangement for the fabric design.

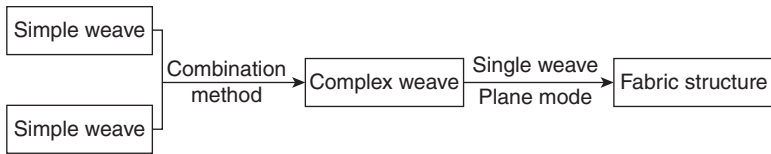
The design of gamut weaves and weave-databases is a distinctive innovation, and represents a major change in design concept and principles away from the more traditional single-weave design. Given the need for high efficiency in production, designs that adhere to the balanced interlacement of warp and weft give rise to free replacement between weaves in an already established weave-database. A weave-database of digital woven fabric is free from restrictions on patterns and allows any pattern with a different layout to be used to design a woven fabric. Research into gamut weaves and weave-databases, based on the nature of digital woven fabric, have laid the foundation for further research into digitising the fabric structure of digitally designed jacquard fabric.

4.3 Compound structure design

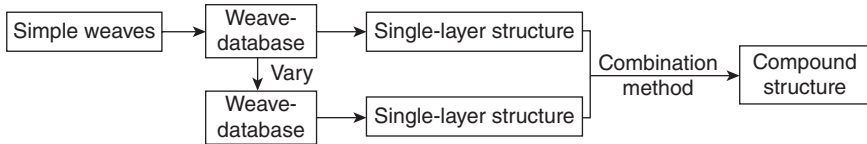
The construction of woven fabric can broadly be classified into two parts: simple structure and complex structure. Complex structure is difficult to approach because of its complicated design processes and design variations. Thus, it is always designed by a combination method. With the layered-combination design method proposed in this book, the structure design of woven fabric can be approached in a digital mode, replacing the traditional single-weave design (Zhou and Ng, 2007f). It is essential that research into the combination methods of gamut weaves in different weave-databases is continued.

4.3.1 Nature of complex weave and digitisation compound structures

The complicated structure of woven fabric is constructed with multi-series of warps/wefts and with complex weaves such as weft-backed weave, warp-backed weave and double-layer weave. Traditionally, complex weaves as well as complicated fabric structures were based on simple weaves. The basic design process starts with the selection of an appropriate simple weave, followed by the design of a compound weave, with a specific inserting ratio of warp and weft threads. This design method is a kind of single-weave design mode. But more than that, compound-weave design is an experience-based process, producing a complicated woven construction. Before weaving, the woven effect cannot be predicted and, therefore, the nature of simple weaves needs to be grasped thoroughly before the design of compound weave is attempted. Although the application of CAD systems has enhanced the design efficiency of complex weave, the single-weave design mode weave via the combination of selected simple weaves remains



4.9 Traditional design processes of complex compound weave and application.



4.10 Design processes of digitisation compound structure.

unchanged. Further, computer-assisted weave design still puts some restrictions on the innovation of fabric structure. The traditional design processes of complex compound weave and its application are shown in Fig. 4.9.

With the proposed layered-combination design mode for digital jacquard textile, an opportunity has arisen to innovate the traditional single-weave design mode. According to the design concept of digital jacquard textile, fabric structure can be produced through the combination of several single-layer structures. The design of gamut weaves and weave-database has replaced the design of a single simple weave. Thus, in the course of designing gamut weaves, the fabric effects of both single-layer and compound fabric structure should be taken into account. Also, the balanced interlacement of threads in compound fabric structure needs to be considered for mass production. The design processes of the digitisation compound structure, based on simple weave design, are shown in Fig. 4.10. What is required is the design of a series of simple weaves, i.e. gamut weaves, and the establishment of a corresponding weave-database. Therefore, when designing a single-layer fabric structure, the gamut weaves serve as the smallest application unit. Since gamut weaves have the same weave repeat and close characteristics of weave variant, as long as a unified starting point is set up for them, single-layer structural design of digital jacquard fabric can conveniently be approached using computer-programmed processing.

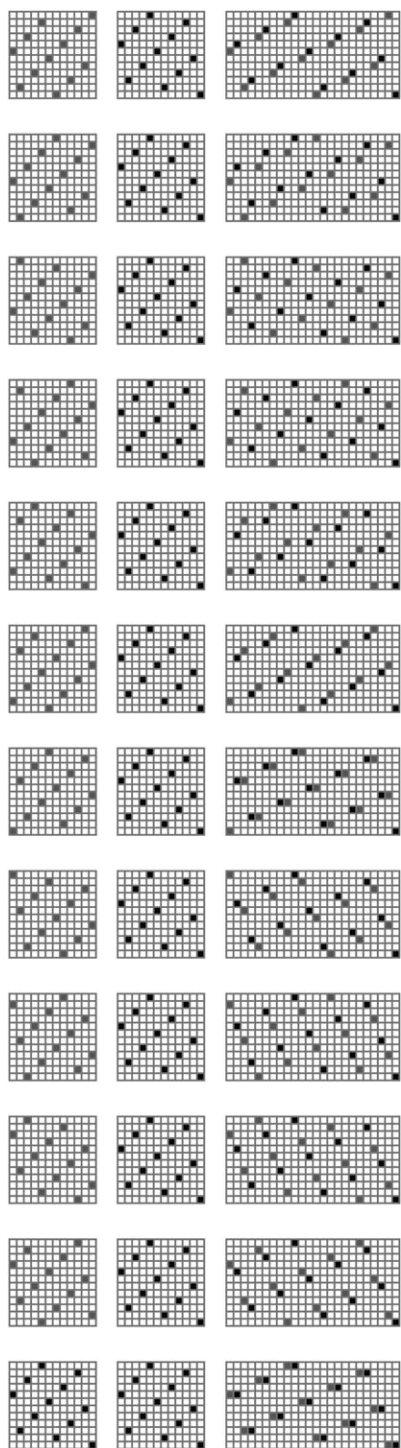
4.3.2 Design principles for digitisation of compound structures

Traditionally, complex weave design was approached through the combination of simple weaves under the single-weave design mode. However, in

structural design of digital jacquard fabric, the design of single complex weave has been replaced by the combination of single-layer structures. Thus, when designing gamut weaves, the combination effect amongst gamut weaves in different weave-databases should be thoroughly considered. According to the combination principle of fabric structure, the neighbouring threads constructed in woven structures can produce two basic effects only, i.e. the juxtaposition effect (a non-backed structure effect) and the mutual covering effect (a backed structure effect). Therefore, the rules of non-backed and backed effects after weave combination are obviously the key technical problems in gamut weave design, and in structure combination of digital jacquard textile. Additionally, since gamut weaves are based on certain primary weaves that are a kind of simple weave (e.g. regular satin weave, twill weave), the weave characteristics of primary weave also represent those of all gamut weaves in the same weave-database. For this reason, based on the combination characteristics of the primary weave, the combination characteristics of gamut weaves in different weave-databases and the combination effect on fabric structure design by the same gamut weaves can be deduced.

Figure 4.11 shows the fundamental design practice of a two-layer combination of fabric structure, in which all of the effects are illustrated with 12-thread sateen as the primary weave of each weave-database. The effect drawings for the derivative weaves of the primary weaves, the primary weaves themselves, and compound weaves, are listed from top to bottom, respectively. The primary weave is 12/5 weft-face sateen, which provides eleven variations of weave through displacing the starting point of the primary weave. This means that a total of 12 digital weave-databases are applicable to be set up (including a weave-database of the primary weave) as R kinds, where R refers to the number of weave repeats. In this way, the 12 derivative weaves of Fig. 4.11 can generate 12 effect drawings of compound weaves upon combination with the primary weave, in accordance with the combination method of 1-and-1 across weft. Two of them have a full-backed effect, featuring superimposition of interlacing points, and ten produce non-backed effect ($R - 2$ kinds). According to the result of the combined application with the primary weave, it could be inferred that the same result can also be achieved with the combination of whole gamut weaves in the same weave-database. Therefore, during the actual design process, the combination effect of primary weaves may provide available reference for designing gamut weaves and the combination of fabric structure.

When combining fabric structures in 1 : 1 : 1 order across three wefts, there will be three types of compounded effects on the wefts: backed effect, backed effect of any two wefts and non-backed effect. Among them, a backed effect of three wefts is produced on the basis of a backed effect of

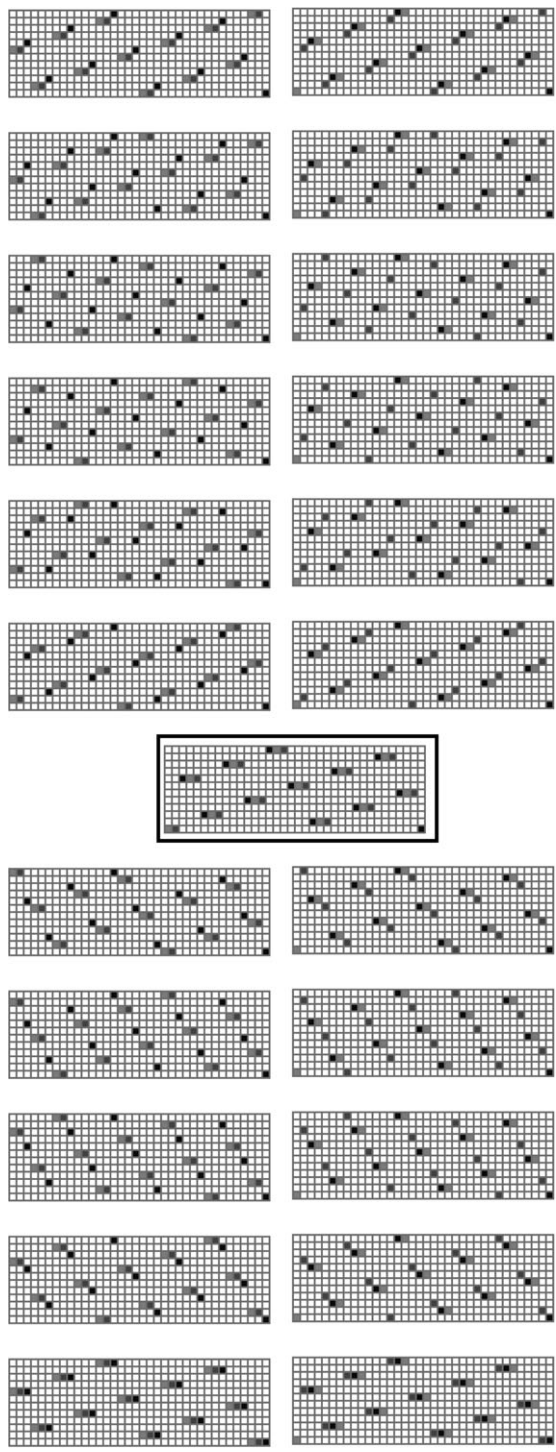


4.11 Combination effects of twelve-thread satin in 1 : 1 order weft-wise.

two wefts, and a backed effect of any two wefts has the same combination principle as that of two juxtaposed wefts. Taking 12-thread sateen as an example, when adding one weft to a combination structure of two wefts, a total of 144 kinds of compound effects can be produced, i.e. $R \times R = 12 \times 12 = 144$, of which there are 33 kinds of backed effect, i.e. $2(R - 2) + R + 1 = 33$. They include $2(R - 2)$ kinds of backed effect being produced on the basis of previous non-backed effect of two wefts, $R - 2$ kinds of backed effects being produced on the basis of the previous backed effect of two wefts, and three kinds of backed effect of three wefts. In short, there are 30 kinds of backed effect of any combined two wefts, i.e. $2(R - 2) + R - 2 = 20 + 12 - 2 = 30$. As for a non-backed effect (juxtaposition), there are 111 kinds, i.e. $(R - 2)(R - 2) + (R - 1) = 111$. These include $(R - 2)(R - 2)$ kinds of non-backed effect being produced on the basis of previous non-backed effect of two wefts and $R - 1$ kinds of non-backed effect being produced on the basis of the previous backed effect of two wefts. The principle of backed effect produced in three wefts combination is that the added weft has the same interlacing points as either the upper or lower weft. Figure 4.12 shows the design practice and effects. In addition, an extra compound effect featuring the same compound interlacing points combined with both upper weft and lower weft, with flamed weave effect, will be produced when combining three wefts (see Fig. 4.12).

Following this same method, when combining fabric structures in a 1 : 1 : 1 : 1 order across four wefts, there will be a total of 1728 kinds of compound effects, i.e. $R \times R \times R = 1728$. On the basis of the compound effects of three wefts, there will be $(R - 2) \times 1110$ kinds of non-backed effects produced, based on the previous non-backed effect of three wefts, i.e. $(R - 2) \times [(R - 2) \times (R - 2) + (R - 1)] = 1110$, while 618 kinds of compound effects of four wefts will be produced, i.e. $R^3 - (R - 2) \times [(R - 2) \times (R - 2) + (R - 1)] = 618$. These include the backed effects of any two wefts, backed effects of any three wefts and backed effects of four wefts. Among the compound backed effects, only four kinds of backed effects of four wefts feature the same interlacing points, and up to R kinds of extra weaves that have the same compound interlacing points combined with both upper weft and lower weft. It should be mentioned that, due to the existence of extra weaves in weave combination, the number of compound effects of two wefts or three wefts in a four-weft combination is difficult to ascertain.

Based on experiments in weave combination, it was found that with more than four wefts for weave combination, it is difficult to anticipate the kind of compound effects that will be produced, particularly partial backed compound effects, due to the random effects generated. Therefore, in the course of digital jacquard textile design, specific effects of partial backed compound effects should be ignored when compounding wefts for more than four groups. The data for combinations of 2–4 layers by different



4.12 Backed effect of 12-thread satin combined in 1 : 1 : 1 order weft-wise (extra weave is framed).

Table 4.3 Data of layered combination with different weave-databases

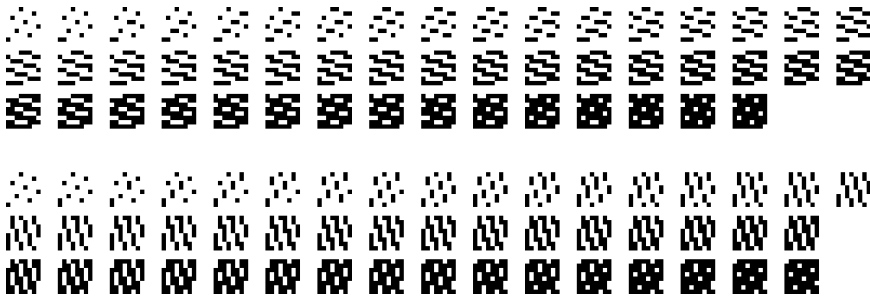
Layers	Combination methods	Non-backed combination	Partial-backed combination	Backed combination
2	R	$R - 2$	0	2
3	R^2	$(R - 2) \times (R - 2) + (R - 1)$	$R^2 - [(R - 2) \times (R - 2) + (R - 1)]$	3
4	R^3	$(R - 2) \times [(R - 2) \times (R - 2) + (R - 1)]$	$R^3 - (R - 2) \times [(R - 2) \times (R - 2) + (R - 1)]$	4

Note: R represents weave repeat.

weave-databases are listed in Table 4.3. Using the proper combination method, the data can be applied to the design of digital jacquard textile with any grouping of wefts. In addition, in order to control the floating length of warp threads, the separation–combination method of weave-database is also available for designing compound structures of digital jacquard textile, i.e. gamut weaves separated with the appropriate ratio to form several sub-weave-databases. This can be applied to designing the respective single-layer fabric structures, before then recombining the single-layer fabric structures with the same ratio of separation to form a compound structure. By this method, for example, a former 1 : 1 combination design of two wefts could be transferred to a 1 : 1 : 1 : 1 combination design of four wefts, but the maximum float length of warps in the two design cases is the same.

4.3.3 Combination methods for digitisation of compound structures

Two design methods can be deployed to design digital gamut weaves, viz. a regular and an irregular weave design method. However, only the regular weave design method can be processed with a CAD system. In the course of regular weave design for gamut weaves, there are three methods available for adding/reducing weaving points, viz. horizontal transition, vertical transition and diagonal transition, and only horizontal and vertical transition can be used for designing compound structures of digital jacquard textile with balanced interlacement. Taking eight-thread weft-faced sateen as an example, Fig. 4.13 shows gamut weaves that are constructed by horizontal and vertical transition. The results show that only the upper series of gamut weaves in Fig. 4.13 meet the requirement of balanced interlacement weft-wise, while the lower series of gamut weaves meet the requirement of balanced interlacement warp-wise. Further employment of the two



4.13 Gamut weaves design of eight-thread satin.

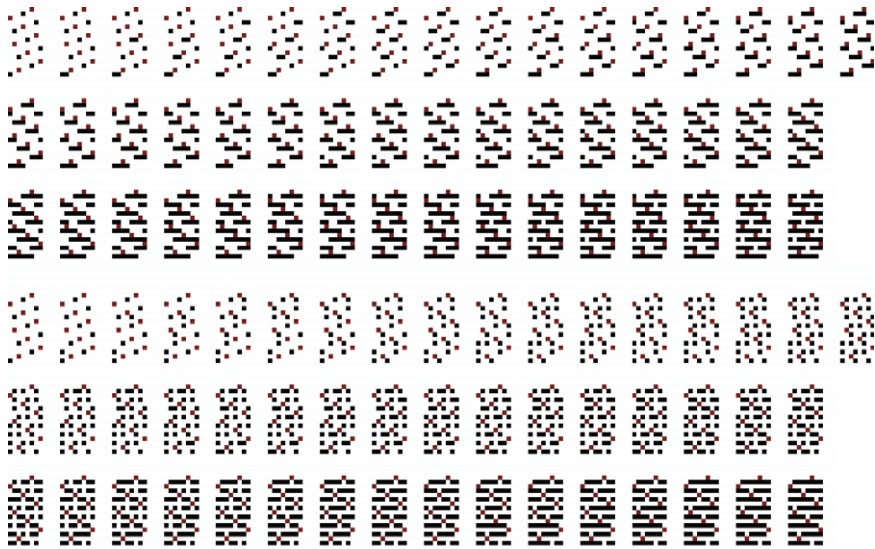
series of gamut weaves to design compound structures of fabric produced compound structures with different results.

Figure 4.14 illustrates two compound structure effects combined with the gamut weaves of Fig. 4.13 and a primary weave of another weave-database, respectively, in the ratio of 1-and-1 across weft. The fixed primary weave employed for the compound structure is designed by changing the starting point of the primary weave of gamut weaves of Fig. 4.13. From Fig. 4.14, the conclusion can be drawn that the upper series of compound weaves exhibits better balance of interlacement than the lower series, of which the fabric structure featured balanced interlacement of both warp and weft. Yet, the upper series of compound weaves fails to maintain the balance of interlacement warp-wise and weft-wise: therefore, it cannot meet the technical requirements for mass production. In other words, the lower series of gamut weaves in Fig. 4.14 cannot be used to design digital jacquard fabric since the weaving loom would not run smoothly in mass production. Having said that, the gamut weaves of a weave-database designed through vertical transition could only be applied to structure combinations warp-wise for digital jacquard fabric, while the gamut weaves of a weave-database designed through horizontal transition could be applied to structure combinations both warp-wise and weft-wise, due to a better balance of structure interlacement.

The results of research indicate that with the appropriate combination method, the compound structure is capable of expressing various woven effects on the face of fabric. It benefits the design creation of digital jacquard textile well. In addition, since the structure design of digital jacquard textiles is determined by gamut weave design and the combination method, any digital image can be used to design digital jacquard fabric.

4.4 Full-colour compound structure design

It is necessary to investigate further the relationship between the design methods for gamut weaves and the combination method of compound

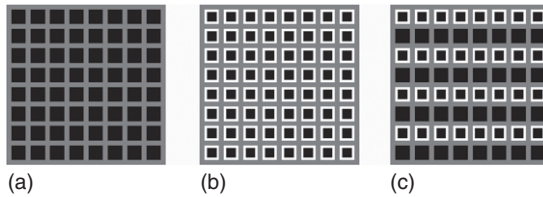


4.14 Combined effects of gamut weaves from an eight-thread satin and a primary weave.

fabric structure, so as to establish the optimal structural design method under the layered design mode for creation of digital jacquard fabric.

4.4.1 The nature of full-colour compound structures

Jacquard fabric is a woven fabric. The colour principle of woven fabric is a kind of colour-mixing of non-transparent colours (Wilson, 2001). This principle is, in nature, very different from that of printing colour and computer colour. However, they also have some points in common: they all use limited primary, or basic, colours and realise rich colour expression by way of mixing colours. The warp and weft of woven fabric reflect the mixed colours by changing their structure and arrangement. When the inter-covering effect produced between warp and weft cannot be controlled, mixed colours cannot be predetermined because of the resulting erratic colour deviation. In any design imitation, colour deviation is more obvious between the final fabric and original artwork. According to the colour-mixing principles of non-transparent yarns, when paired colour threads are viewed at a distance, only the mixed colours that vary with the floats of colour threads can be seen. Thus, jacquard fabric exhibits a rich mixed colour effect. By such principles, full-colour structure necessitates the involvement of all the threads for colour mixing. The merit of this kind of structure is that changes of the colour ratio of each yarn produce no inter-covering amongst juxtaposed colour threads in the construction.



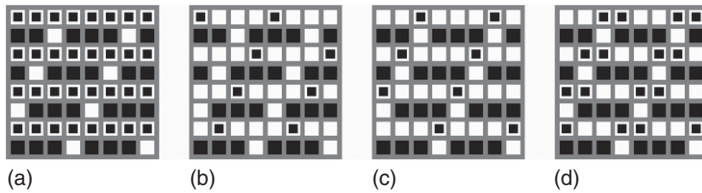
4.15 Colour expressions of two juxtaposed wefts.

Figure 4.15 shows the colour effect of two wefts ranged in juxtaposition; (a) and (b) are lined in 1-and-1 that formed (c), showing a kind of mixed colour effect. At a distance, only the mixed colour effect can be seen instead of the original individual colours of (a) and (b). It is apparent that the mixed colour effect of (c) will vary with any changing of colour ratio of (a) and (b). According to this method, manipulating the colour changes of (a) and (b) can realise a range of colour in (c). The full colour effect of such colour-mixing relates to the compound ‘full-colour’ structure. It should be noted that before defining the design effect of fabric, any colour can be selected for (a) and (b). The maximum number of mixed colours of (c) remains constant, irrespective of the colour change of (a) and (b). This result lays the foundation for structural innovation in digital jacquard fabric.

When the juxtaposed threads are combined with a no-covering effect in the woven structure, such colour-mixing can be thought of as a kind of combined thread with full-colour effect. By changing the colouring ratio between the two threads, various colour effects can be obtained. This fabric construction has been called a ‘full-colour structure’. With this structure, a digital jacquard fabric with a print-like colour shading effect can be realised with only limited colour threads. Various innovative designs can also be produced. This innovative structural design method is thus suitable for both colour simulative design and colour innovative design of digital jacquard fabric, enabling woven fabric to be designed and produced as conveniently as printing.

4.4.2 Design principles for full-colour compound structures

The next step is to determine what kind of fabric structure can satisfy the full colour effect of threads: our analysis suggests that a fabric constructed with a non-backed and gamut shaded effect is effective. In principle, such effects can be found only in fabrics that are processed by the layered-combination design mode. In compound fabric construction, there is at least one interlacing point in opposite configuration on both sides of a line ranged in an alternate order, e.g. one warp interlacing point in a horizontal line corresponds to the lines above and below, with at least one weft

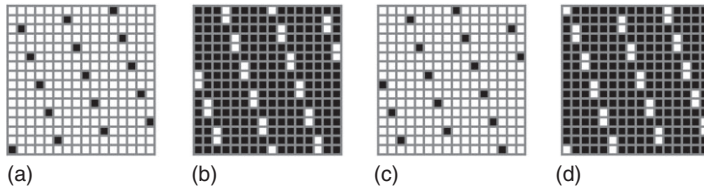


4.16 Structure design for fabric with two colour wefts. (a) Original weave effect; (b) backed effect; (c) partial backed effect; (d) non-backed effect.

interlacing point, and *vice versa*. In Fig. 4.16, the structure of odd numbered horizontal lines is fixed: (a) is in the state prior to design; (b) is designed for an all-backed structure effect; (c) is for a partial-backed effect in which only the interlacing points on one side are in opposite configuration; and (d) is for a non-backed effect that, in the odd number structural lines, the interlacing points above and underneath both have an opposite configuration status. Thus, only (d) represents a non-covering structure of paired parallel wefts that can satisfy the requirement of a full colour effect.

Given this aforementioned principle and alternately arranged interlacing points between the two lines, the weaves that are to be used for combination can be designed. These are called the 'primary weaves'. As part of the design process, it is necessary to set up some kind of technical full-colour points for the primary weaves whilst designing the gamut weaves, to be in line with the requirement of having at least one interlacing point in contrasting configuration after combination. Any compound weave designed from the primary weaves will exhibit a non-backed structure and full-colour effect. Similarly, shaded gamut weaves devised from a primary weave and its weave-database can be built so long as the full-colour points exist in the same combination method as that of the compound single weave. The weaves in different weave-databases can be combined freely, and compound weaves can all exhibit the non-backed effect. By further fixing the starting points, the gamut weaves in different weave-databases can be deployed directly to design a single-layer fabric structure. After combination of single-layer fabric structures in the same way as that of a compound weave, the compound structure of digital jacquard fabric is capable of exhibiting a non-backed and full-colour effect.

Sixteen-thread satin is taken as an example to further explain the design method for full-colour points setting (Zhou *et al.*, 2005). As shown in Fig. 4.17, there are two primary weaves with their full-colour points set, respectively. First of all, two primary weaves with the same weave but with different starting points (I and II) are selected. The primary weave selected can be twill or satin, belonging to the three elementary weaves with the same weave repeat of warp and weft. In order to control the length of floats on the fabric



4.17 Primary weaves and their full-colour points. (a) Primary Weave I; (b) full-colour points of Primary Weave I; (c) Primary Weave II; (d) full-colour points of Primary Weave II.

surface, the best repeat range of primary weave should be between 5×5 and 48×48 . For a weave repeat that is over 48×48 , the floats will be too long to construct the structure of fabric and are of little application value.

Next, the full-colour points (similar to a kind of weave) for Primary Weave I, in line with the feature of Primary Weave II, are set. This method is to reverse the interlacing points in Primary Weave II and to enhance it upward along the warp direction (see (b) in Fig. 4.17). Similarly, set the full-colour point for Primary Weave II in line with the feature of primary weave I. This method is to reverse the interlacing points in I and to enhance it downward along the warp direction (see (d) in Figure 4.17).

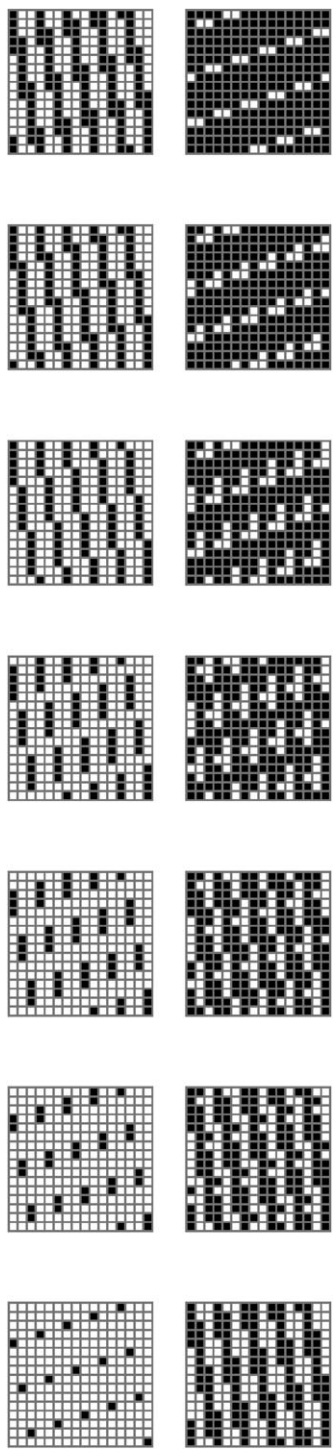
The design of a compound full-colour structure is inspired by the no-covering structure of woven fabric. After setting the technical full-colour points, the respective gamut weaves and their weave-databases can be designed on the basis of the two primary weaves; and the weaves in different weave-databases can be combined freely to create a non-backed and full-colour structure that satisfies the full-colour effect of digital jacquard fabric. Furthermore, the full-colour structure remains, even though the images have been changed. In other words, full-colour structure design is determined by the weave design and combination rather than by the motif.

4.4.3 Design methods for full-colour compound structures

After confirming two primary weaves and their respective full-colour points, the gamut weaves for a structure design can be carried out. In this book, the gamut weaves in the two weave-databases have been called basic weaves and joint weaves, respectively.

Design approach for basic and joint weaves

Based on Primary Weave I, shown in Fig. 4.17, a series of shaded weaves have been designed without destroying the full-colour points. As stated, such weaves are called 'basic weaves' (see Fig. 4.18). The enhancement



4.18 Design of basic weaves based on Primary Weave I.

direction originates from the right to the left, in order to make the interlacing points continuous for the best interlaced balance. Given that R and M represent weave repeat and the enhancement number of shaded interlacing points, respectively, when $M = R$ the number of basic weaves is the minimum, $R - 2$; when $M = 1$, the number of basic weaves is the maximum, $(R - 2) + (R - 3)(R - 1)$.

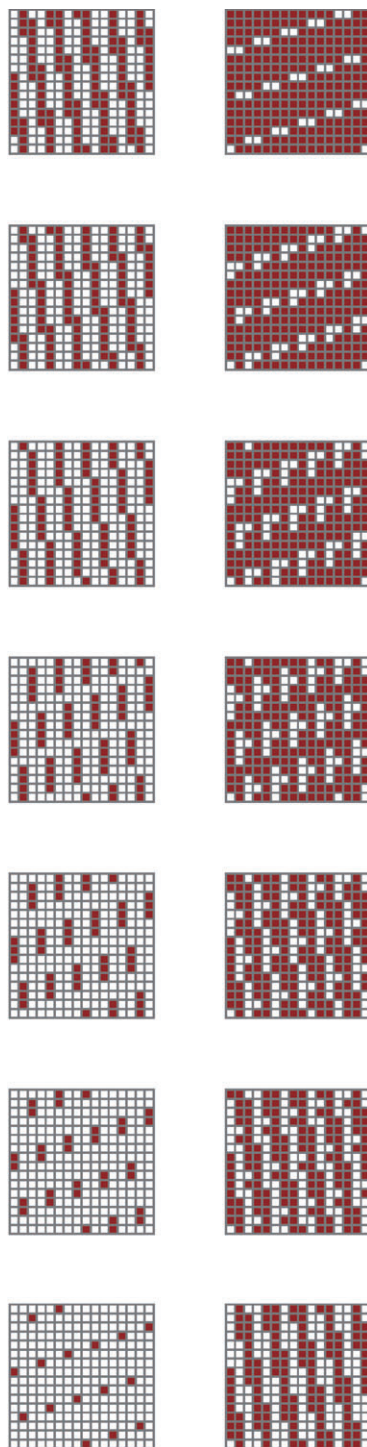
Based on basic weave II in Fig. 4.17, a group of shaded weaves originating from left to right is designed, without destroying the full-colour points. Such weaves are called 'joint weaves' (see Fig. 4.19). The enhancement direction is opposite to that of the basic weaves, to optimise the colour effect of fabric after combination. When $M = R$, the number of joint weaves is the minimum, $R - 2$; when $M = 1$, the number of joint weaves is the maximum, $(R - 2) + (R - 3)(R - 1)$.

Application of basic and joint weaves

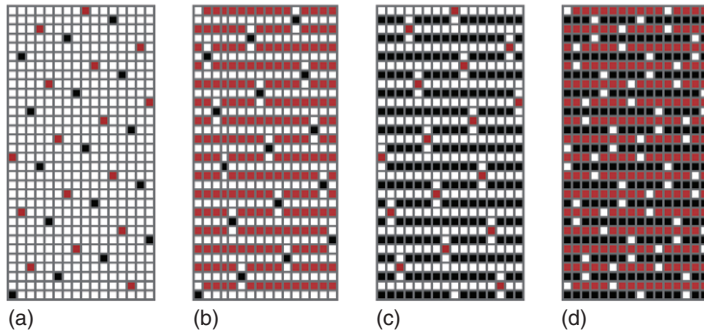
After designing the basic and joint weaves, and before their application, a simple verification of the compound full-colour structure can be made. Since both basic weaves and joint weaves have their own specific full-colour points, as long as the starting point is the same during the combination, the validity of the full-colour points in designing a fabric structure can be verified by the combination of single weaves. The verification methods are to use the first and last weave of the basic weaves to combine with the first and last weave of the joint weaves, respectively. Figure 4.20 shows the four kinds of effects created. When the requirement of a non-backed effect for interlacing points in a compound weave is met, all the basic weaves and joint weaves are in line with the aforementioned methods, and they can fully satisfy the full-colour effect in an unrestricted combination.

Two conclusions can be made for full-colour compound structure. First, where a verified 1 : 1 combination of basic weaves and joint weaves is valid, any alternately matched basic and joint weaves in a 1 : 1 pairing order, such as 1 : 1 : 1 : 1 and 1 : 1 : 1 : 1 : 1 : 1, are also valid. Second, with the same full-colour points, as long as the minimum number of combination effects of basic and joint weaves are valid, the maximum number of combination effects of basic and joint weaves is also valid. Following consideration of these conclusions, several experiments of weave combination were conducted to validate the result inferred in theory. The combination effects are shown from Fig. 4.21 to Fig. 4.24.

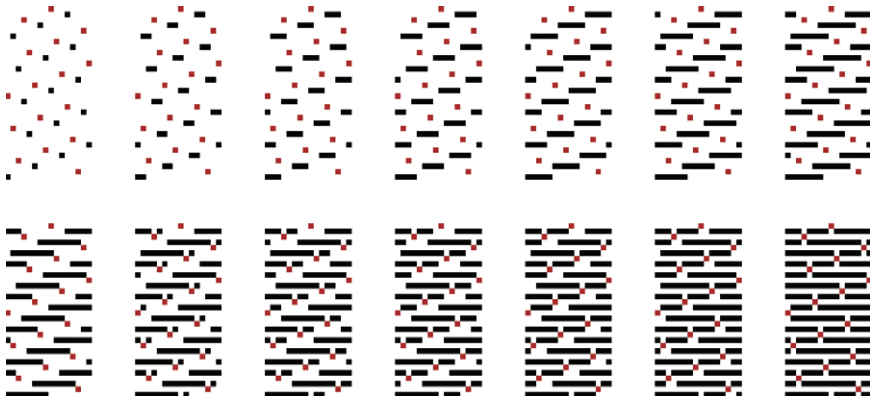
The verification shows that, since full-colour points exist in basic weaves and joint weaves, a non-backed effect can be satisfied after combination, and such a feature can be applied in fabric structure design. So long as the same starting points of the weaves are confirmed, the basic weaves and joint weaves can be used to design single-layer structures of fabric. To further



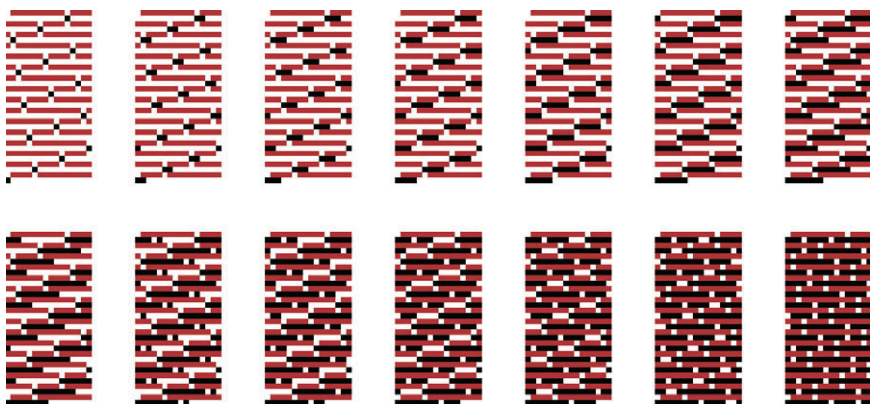
4.19 Design of joint weaves based on Primary Weave II.



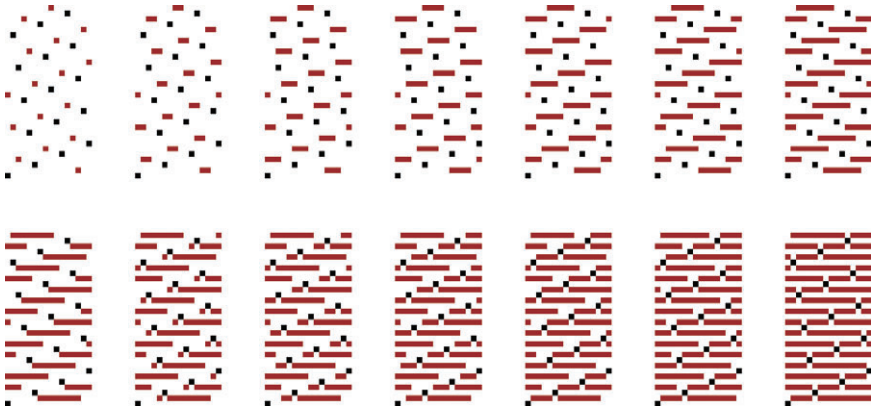
4.20 Non-backed effects of combination of basic and joint weaves. Effect of combination of: (a) first basic weave and first joint weave; (b) first basic weave and last joint weave; (c) last basic weave and first joint weave; (d) last basic weave and last joint weave.



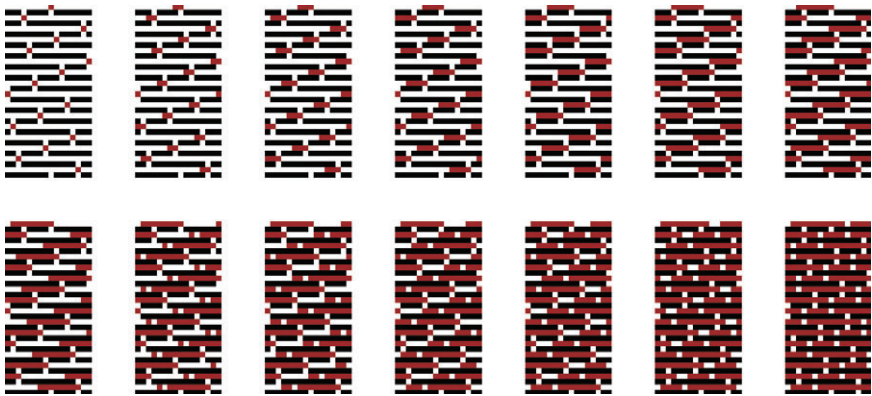
4.21 Non-backed effects of combination of basic weaves and first joint weave.



4.22 Non-backed effects of combination of basic weaves and last joint weave.



4.23 Non-backed effects of combination of first basic weave and joint weaves.



4.24 Non-backed effects of combination of last basic weave and joint weaves.

combine the designed single-layer fabric structures in specific arrangement, i.e. with a combination ratio in the weft direction of 1 : 1 or 1 : 1 pairing (1 : 1 : 1 : 1 or 1 : 1 : 1 : 1 : 1 : 1) while the designed fabric structure of basic weaves and joint weaves are alternately arranged, a non-backed effect of interlacing points will be produced in the fabric construction after combination of single-layer structures. Such effect is not dependent on motifs in the pattern. Moreover, in accordance with the feature of a full-colour structure, the maximum number of mixed colours on the face of a digital jacquard fabric, with different repeat weaves, can be accurately calculated by the formula $[(R - 2) + (R - 3)(R - 1)]^L$, where L stands for the number of fabric

structures used for combination. Even numbers (2, 4, 6, 8 and so on) are preferred. With regard to design application, the full-colour compound structure, together with the information of weft selection, can be directly applied to producing multi-weft jacquard fabrics with full-colour effect. When the full-colour compound structure is rotated by 90 degrees, multi-warp jacquard fabrics with full colour effect are produced.

The success of full-colour compound structure can be regarded as a major breakthrough in the field of innovative design research for digital jacquard fabrics. When designed using the layered-combination design method, and with a full-colour compound structure, digital jacquard fabrics are capable of producing millions of mixed colours on the surface of the fabric for various pattern motifs. Thus, digital jacquard fabric can now be designed and created as conveniently as digital printing.

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Colourless and colourful digital design of jacquard textiles

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Abstract: This chapter reviews practical research in colour design and, in particular, colour mixture theory and the phenomenon of woven structure. It includes two integrative studies into design practices in both the colourless design mode and the colourful design mode.

Key words: digital, jacquard, design, colour mixture theory, colour mode, colourless design.

5.1 Introduction

This chapter discusses practical research in colour design and, in particular, colour mixture theory and the phenomenon of woven structure. It includes two integrative studies into design practices in both the colourless design mode and the colourful design mode.

5.2 Colour mixture theory for digital jacquard textiles

In the design of digital jacquard textiles, the nature and principle of colour mixture appropriate for the fabric cannot be neglected. Not only do these principles govern the colour expression on the face of the fabric but they also advance the innovation of structural design methods for jacquard fabrics. The expression of woven patterns and the colours of jacquard fabric interlacing through warp and weft threads must be realised based on the woven construction and deployment of colour threads, both warp-wise and weft-wise. Generally, in traditional plane design mode, the number of mixed colours on the face of a jacquard fabric was less than 100, due to mutual covering effects caused in the fabric's construction. Thus, the colour design of jacquard fabric was an experience-based undertaking, and research in colour mixture theory was irrelevant for jacquard fabric design.

However, with the proposed layered-combination design mode, especially for the full-colour compound structure design method, digital jacquard is able to express true-colour effects with millions of mixed colours. The colour performance of digital jacquard textiles can now exceed the scope that the eye can distinguish, and has surpassed the design competence

of skilled manual labour. Mastering the nature of colour mixing has become one of the most important factors in the design creation of digital jacquard textiles.

Research into the colour mixture of jacquard fabrics has taken two major directions: the first is colour simulation through a computer-based system on a fixed fabric structure; the second is simulation design of jacquard fabric based on limited primary colour threads. These two research directions aim to increase the design efficiency of jacquard fabric, yet are very much based on the traditional plane design mode of jacquard fabric. The first direction addresses the design problem of colour matching of jacquard fabric: based on a fixed fabric structure, computers can be used to simulate changing colour effects through the variation of warp and weft threads, without the need for actual production. Although the design efficiency of colour simulations of jacquard fabric has increased, colour mixture theory, due to the lack of innovation in fabric structure, is the same as that of traditional design methods for jacquard fabric. The second research direction focuses on the establishment of an ideal colour model with limited primary colours, targeting the design of jacquard fabric to imitate given images via the disposition of limited primary threads. At present, there are two types of proposed colour model, viz. primary colour model and designated colour model. The primary colour model involves part, or all, of the fixed primary colours of red, magenta, yellow, cyan, blue and green with the support of black and white. The designated colour model consists of changeable colours selected on the basis of the colour effect of an objective image, normally with 4–8 designated colours in the model. Due to the lack of design innovation in fabric structure, even when the colour model is in theory optimal, the available structure design fails to support it. To avoid the insufficiencies inherent in design application, the use of a colour table/chart has been proposed, i.e. designing and weaving fabric colour samples to form a fixed colour table/chart prior to the design of the fabric. However, such a method has been useful only for designing jacquard fabrics with the same fabric technical specification.

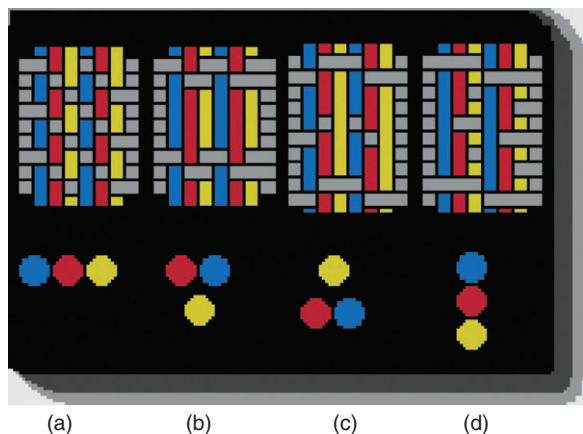
In terms of colour design theory, the simulative effect of jacquard fabric can be better realised by the use of more threads of primary colours. However, when more colours are used as warp and weft threads, the compound fabric structure becomes so complex that it is difficult to attempt. Therefore, a balance point between the number of primary colours and the design of the fabric structure should be considered for colour mixing on jacquard fabric. Such a balance point can be realised only through an innovative design of the fabric structure. Thanks to the proposed layered-combination design mode, restrictions in the structural design of jacquard fabric have been freed. Now, jacquard fabric is able to express millions of mixed colour effects accurately. Based on such an innovative structure

design method, the research into colour mixture theory for jacquard fabric now has very good application value and design compatibility.

The colour mixing of jacquard fabric is different from that of colour mixing in artworks created in other media, such as in painting, printing, or on the screen display of a computer. In terms of colour science, there are three typical colour mixture theories: the additive colour mixture of light (corresponding to a computer's RGB digital colour mode); the subtractive colour mixture of pigment (corresponding to a computer's CMYK digital colour mode); and optical colour mixture (with no corresponding digital colour mode) (Green, 1999). Essentially, additive and subtractive colour mixtures are physical phenomena. However, optical colour mixture is a kind of physiological phenomenon, i.e. it is a colour illusion caused by the visual deficiency of the human eye. In terms of the colour characteristics of jacquard fabric, its colour mixture is an optical colour mixture. Optical colour mixtures can be divided into two types, in terms of their application: juxtaposition mixture and rotatory mixture: the former is a kind of static spatial colour mixture, while the latter is dynamic. Since the colour mixture of jacquard fabric is a static phenomenon, it has to do with the theory of static colour mixture. Therefore, the colour mixing of jacquard fabric can be seen as a kind of juxtaposition mixture of optical colour mixture. The physical colour mixing principle is inadequate to explain the changes of colour on jacquard fabric. In order to investigate the changing rule of mixed colour and colour mode during the design process of jacquard fabric, the influences pertinent to the colouring effect of jacquard fabric (such as the design of the fabric structure, the disposition of the colour threads, and even the fabric technical specification itself) should be taken into account.

5.3 Structure and colour in digital jacquard fabrics

Naturally, the woven structure of jacquard fabric is the foundation for colour mixture theory since the colour mixing of jacquard fabric is based on a woven structure interlaced with warp and weft threads. For jacquard fabric, there are three types of compound structures: the juxtaposition and non-backed effect (Fig. 5.1 (a)), juxtaposition and partial backed effect (Fig. 5.1 (b) and (c)), and juxtaposition and backed effect (Fig. 5.1 (d)). In general, the fabric structure of jacquard fabric designed by the traditional plane design mode is of either backed or partial backed effect. The entire compound structures, such as weft-backed, warp-backed and double-layer structures, should be produced on the basis of a backed or partial backed structure. When designing fabric structures with a non-backed effect under the traditional plane design mode, the change rules of woven threads in the compound structure will be beyond control. Such compound fabric structures cannot be drawn on point paper manually. However, when designing



5.1 Colour effects of compound structures of jacquard fabric.
(a) Non-backed; (b) partial-backed; (c) partial-backed; (d) backed.



5.2 Colour mixture principles of full-colour compound structure.

fabric structures under the digital layered-combination design mode, with the application of a full-colour compound structure, the resulting compound fabric structure shows a non-backed effect, enabling jacquard fabrics to express full-colour effects with the change of floating length of juxtaposed threads.

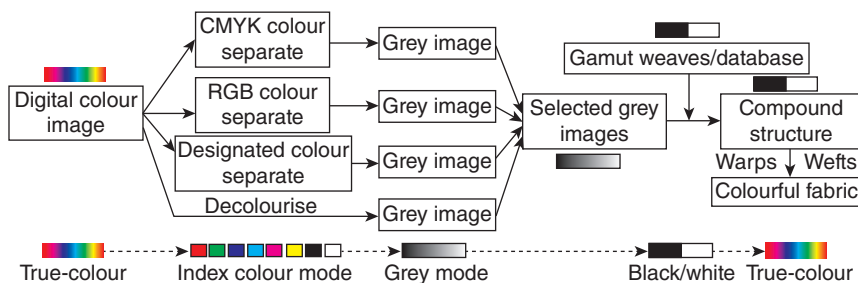
By nature, the layered-combination design mode for digital jacquard fabric is devised around the juxtaposition of coloured threads. The colour mixing of digital jacquard fabric is based on a full-colour compound structure in which the floats of colour threads arranged in juxtaposition can vary freely, whilst the non-backed structure effect remains unchanged. Figure 5.2 shows the basic principle of colour mixing and colour changing in a full-colour compound structure. The colouring model consists of four wefts and one warp that meet the technical requirements of structure digitisation for jacquard fabric design. The gamut weaves used for each thread in the compound structure can be easily established. Taking the brightness of a digital grey image as the standard, the replacement of the greyscales of the digital image and the gamut weaves can be processed efficiently. Combining several monochromatic single-layer structures can produce a colourful fabric with a compound structure. Since the colour mixing of digital jacquard fabrics regularly features a full-colour effect, it can be viewed as an artwork in

which the artifact is made through the digitisation of a woven structure. The mixed colour effect of digital jacquard fabric, with its interlacing of warp and weft threads, cannot be substituted by any other artistic means.

5.4 Colour mode changes in digital jacquard textile design

In addition to colour mixture, the change of colour mode as part of the design process of the layered-combination design mode of digital jacquard is of considerable interest. Figure 5.3 shows how any true-colour digital image can either be separated into several achromatic paths to form colourless grey-mode digital images, or be decolourised completely to produce a grey digital image without colour separation. Next, based on the brightness of the grey-scales, a colourless grey image can be designed into a single-layer fabric structure via structure digitising. After that, a compound structure can be created in appropriate proportions by combining several single-layer fabric structures. Finally, colourful digital jacquard fabric can be produced by the deployment of coloured warp and weft threads. The structure produced is capable of showing rich mixed colours, with its potential colour number reaching the mega level. In the whole design process of the layered-combination design mode, the colour mode originates from a true-colour effect digital image, to a grey effect digital image, and finally to black and white (in both single-layer and compound structure) reflecting a state of *no colour in the eyes, but in the depth of the heart*. By then, the compound structure is able to express millions of mixed colours similar to the ‘true colour’ effect of the original digital image.

Moreover, it should be noted that in the course of the layered-combination design mode, the shape and colour of the digital image are separated: the key is the digitised structure. When processing the structure design, only the shape of the digital image is used. The colour effect of the digital image

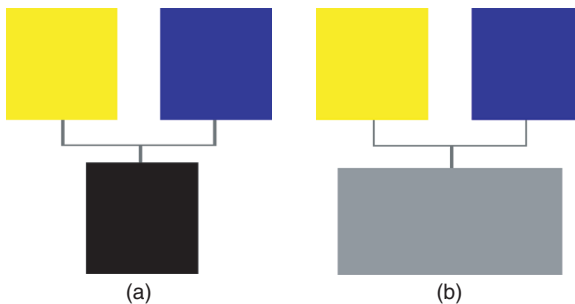


5.3 Colour mode change in the course of digital jacquard fabric design.

and the final colour effect of the digital jacquard fabric may either be the same or different, depending solely on the purpose of the design. Both colour simulative design and colour innovative design of digital jacquard fabric share the same colour mixture theory and colour mode changing performance.

5.5 Colour mixing in digital jacquard textile design

The colour mixture theory of woven fabric has to be established based on the employment of the limited colours of warp and weft threads. Among primary colour theories, the digital primary colour modes, both RGB and CMYK, can provide available references to the colour design because there is no existing colour mixture theory available specifically for designing digital jacquard fabric under layer-combination design mode. When designing simulative fabric, the CMYK digital colour mode, based on subtractive colour mixture theory and used for output of digital images, seems the optimal choice. Since the colour mixing of woven fabric is subject to optical colour mixture theory, research into the differences between subtractive and optical colour mixture is thus the key for digital jacquard fabric colour to reproduce accurate colour effects of digital images. Figure 5.4 shows the mixed colour effect of two contrasting colours with the same area and lightness. The resultant mixed colour, under subtractive colour mixture, results in black with the same area, in theory. Under optical colour mixture theory, however, the mixed colour effect is dark grey and the mixed area is the sum of the two original areas. For this reason, the colour mixing of digital jacquard fabric interlaced with warp and weft threads is a spatial colour mixture with no superimposition. The main characteristic of this kind of colour mixture is that, after colour mixing, the luminosity is invariable but the mixed area is increased. Therefore, colour saturation is reduced when mixing colour with warp and weft threads. Further, the available range of



5.4 Colour effects of subtractive mixture and optical mixture.
(a) Subtractive mixture. (b) Optical mixture.

colour saturation and the scope of brightness of the mixed colours are both reduced.

With reference to the colour mixture theory stated earlier, when designing digital jacquard fabric in the layered-combination design mode, the resulting compound structure of jacquard fabric is capable of expressing millions of mixed colours based on its compound structure. If applying a non-backed compound structure, fine colour shading effects can be produced. However, the colour mixing of digital jacquard fabric formed by the deployment of warp and weft threads is different from that of RGB additive colour mixture, or of CMYK subtractive colour mixture. It is based on a 3-D woven structure that brings about a distinctive quality for digital jacquard fabrics and, therefore, the colour mixing of digital jacquard fabrics features the perfect integration of textile materials and woven fabric structures that cannot be imitated by other means of artwork. Similarly, the simulation design of digital jacquard fabric can produce only a similar, but not an exact, copy of the same colour effect, of the original digital images.

5.6 Design of colourless digital jacquard fabrics

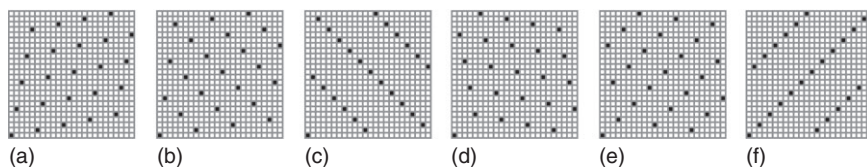
Practical research into colourless digital jacquard fabric design was carried out to investigate the relationship of structural design and fabric effect towards the creation of an appealing colourless digital jacquard fabric. To this end, two requirements were addressed: the expression of the woven image and the capability of mass production.

5.6.1 Choice of digital images

There are no restrictions on the images that can be used for colourless digital jacquard fabric design. Abstract or objective images of any sort, such as portraits, landscapes, flowers, manuscripts, can all be selected for fabric design. However, given the black-and-white shading effect and the further technical analysis of structure, a portrait image is the optimal choice. If the simulative design of a portrait motif can be produced satisfactorily, the method of its structural design will satisfy the design of any other images. Conversely, however, even if the structural design method satisfies other images such as landscapes or calligraphy, it does not necessarily mean that it will be suitable for simulating portrait images (Zhou, 2007e).

5.6.2 Selection of structure design methods

The design of gamut weaves is the first stage in the course of structure design. Gamut weaves contain a series of derivative weaves based on primary weaves that feature similar weave characteristics. Thus, not only

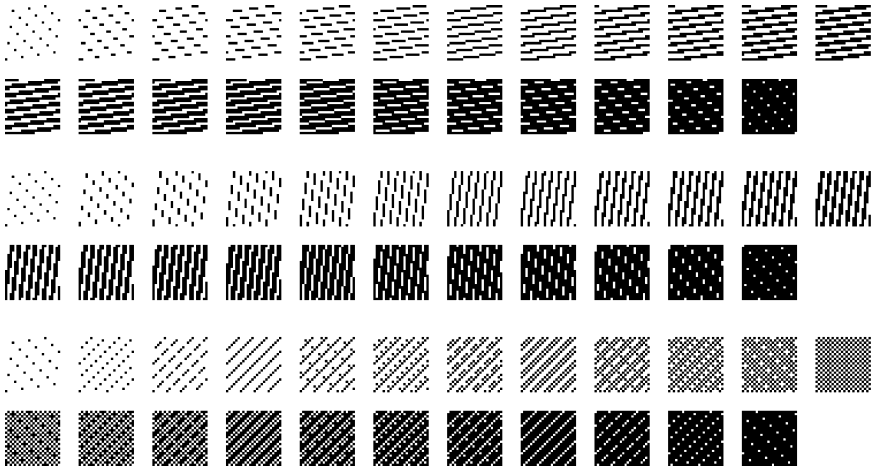


5.5 Six kinds of 24-thread satins with different step numbers.

can they be applied to set up corresponding weave-databases, but they can also be employed to design single-layer fabric structures. Theoretically, a primary weave of a simple satin weave can support $4 \times R! \times M_s \times M_w$ weave-databases, of which each has a maximum of $R \times (R - 2) + 1$ weaves (where R refers to weave repeat, M_s refers to the number of elementary satins that feature identical weave repeats but a different step number, and M_w refers to the number of weaves via changing the weave starting point, $M_w = R$). Thus, in design practice, it is important to optimise the design method of the weave-database rather than establish all the weave-databases.

Taking 24-thread satin as an example, six kinds of satin weaves can be drawn as a primary weave under different step numbers (Fig. 5.5). In terms of weave effect, six kinds of 24-thread satin weaves can form three pairs: (a) and (d); (b) and (e); and (c) and (f). Each pair of weaves shares the same weave effect but different slanting directions of interlacing points. For a balanced distribution of interlacing points, the weave effect of (a), (b), (d) and (e) are preferred to (c) and (f) in Fig. 5.5. Thus, given the technical specification of the fabric in design practice, the weave in Fig. 5.5(a) is selected as the primary weave for designing gamut weaves and for establishing a corresponding weave-database.

Discounting the irregular design method, in which weaving points vary without rules, there are three design methods that can be used for designing gamut weaves: the three regular transition directions (vertical, horizontal and diagonal) for adding/reducing interlacing points. Each of them can be used to build corresponding weave-databases based on the same primary weaves. Figure 5.6 shows, for example, (from top to bottom) the gamut weaves designed through vertical transition, horizontal transition and diagonal transition based on the primary weave shown in Fig. 5.5(a). The value of adding/reducing interlacing points in each of these gamut weaves is the same, i.e. $M = R = 24$. Thus, the black-and-white gradation effects of the three series of gamut weaves are the same. When applying these three series of gamut weaves to the design of colourless digital jacquard fabric, the effects produced should, in theory, be the same if the digital images are the same. If there is a difference among the effects of the three digital jacquard fabrics produced, it could be concluded that the design method of the gamut weaves affects the fabric effect.

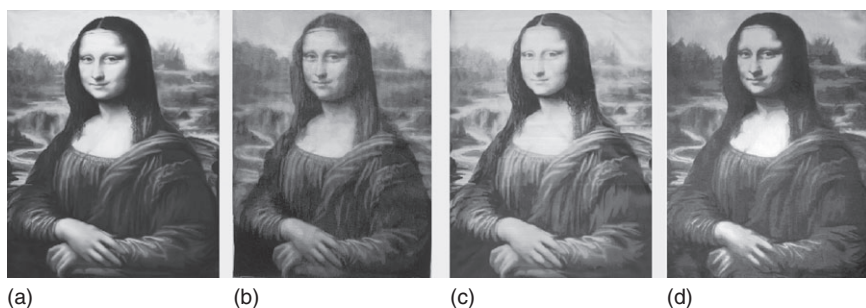


5.6 Three series of gamut weaves designed by three transition directions.

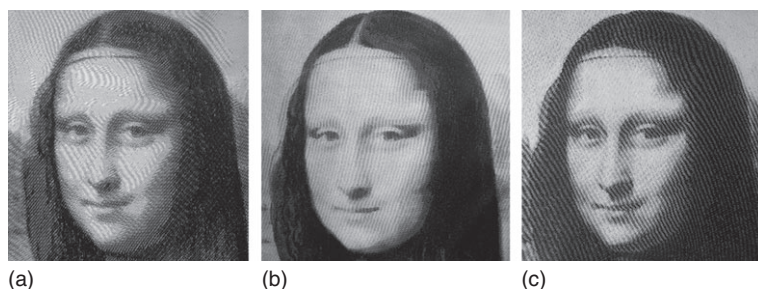
5.6.3 Comparison of effects in fabrics

Balanced interlacement is one of the key technical points for the production of jacquard fabric, and it must be fulfilled satisfactorily in any fabric structure design. Under the digital design approach, computer-aided design has replaced structure drawing on point paper: thus, the balanced interlacement of warp and weft is essentially now dealt with in the course of the design of gamut weaves. Figure 5.6 illustrates three series of gamut weaves designed from primary weaves of 24-thread sateen. The number of gamut weaves is 23 for each series. Reducing the value of interlacing points can enlarge the number of gamut weaves. When $M = 1$, the number of gamut weaves changes to 529, i.e. $R(R - 2) + 1 = 529$; when $M = 12$, the number of gamut weaves changes to 45, i.e. $2(R - 1) - 1 = 45$; when $M = 6$, the number of gamut weaves changes to 89, i.e. $2[2(R - 1) - 1] - 1 = 89$.

The number of gamut weaves is 23 in each weave-database used to design colourless digital jacquard fabric, with the same portrait and the same fabric technical specification. The thread density is 115 threads/cm in both warp and weft directions. The warp threads are black and weft threads are white. The fabric effects produced are shown in Fig. 5.7. Here (a) is the original digital image in grey colour mode; (b)–(d) show the fabric effect designed by using gamut weaves with diagonal, horizontal and vertical transitions, respectively. Taking the simulated effect as the criterion to evaluate overall effect, (d) is considered to be the best; (c) is the worst; and (b) is barely satisfactory, with an unbalanced interlacement of warp and weft threads that may well affect the efficiency of fabric production.



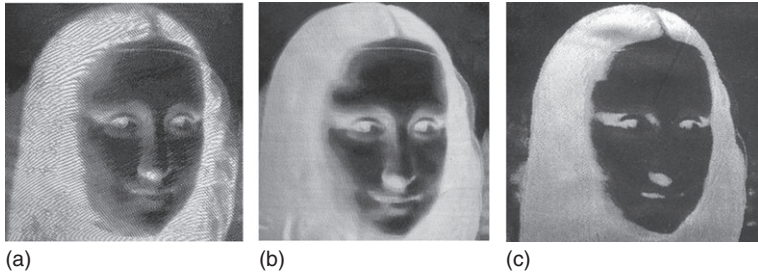
5.7 Fabric effects designed by different gamut weaves. (a) Original digital image; (b) diagonal transition; (c) horizontal transition; (d) vertical transition.



5.8 Details of the face side of the fabric. (a) Diagonal transition (b) horizontal transition (c) vertical transition.

Further, it was found that the simulated effect of colourless digital jacquard fabric is determined by the expression of black-and-white shading reproduced on the face of the fabric; this was also manifested in the detail of the fabric structure. Figure 5.8 (a), (b) and (c) show detailed face effects produced with a diagonal, horizontal and vertical transition, respectively. Taking the reproduced black-and-white shading effect as standard: (a) is satisfactory; (b) has the worst simulated effect in light areas but is better in dark areas; whilst (c) has the opposite effect, having the worse simulated effect in dark areas but the best in the light areas. Since the three series of gamut weaves designed had the same black-and-white shading effects, it is apparent that the black-and-white shading effects of the final fabric can be affected by the three-dimensional woven structure used for production.

Additionally, since the design of colourless digital jacquard textile was based on a single-layer fabric structure, the face and back effects of the fabric were reversed, showing a negative effect. Figure 5.9 shows the details of the reversed sides of fabrics, showing the detailed back effect designed by (a) diagonal transition; (b) horizontal transition; and (c) vertical



5.9 Details showing the reverse side of the fabric. (a) Diagonal transition; (b) horizontal transition; (c) vertical transition.

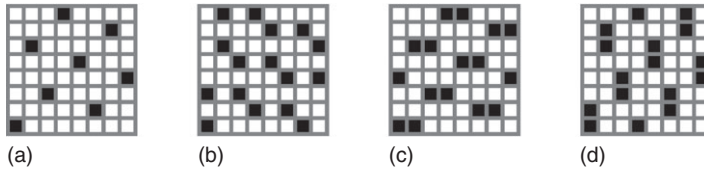
transition. Compared with the black-and-white shading effect on the face side, (a) results in little difference; (b) results in an opposite effect to the face side, i.e. a worse simulated effect in dark areas but better in light areas; and (c) also results in an opposite effect to the face side, i.e. a worse simulated effect in light areas but better in dark areas.

The difference in the black-and-white shading effect observed on the face and reverse sides of the fabric suggest that the design of the gamut weaves has an impact on the black-and-white shading effect of jacquard fabric. The conclusion that can be drawn from this is that, in the course of black-and-white simulative design of colourless digital jacquard fabric, the black-and-white shading effect of gamut weaves cannot simply represent the shading of the final fabric because there is a gap between paper drawing and final woven structure.

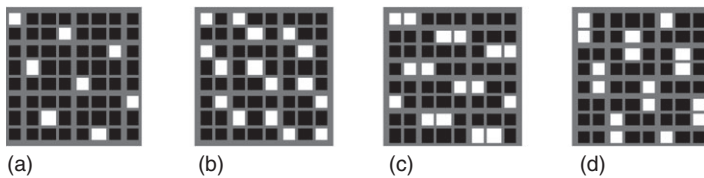
5.6.4 Technical evaluation

The three series of gamut weaves share the same black-and-white effect; however, the black-and-white shading effects of the fabrics produced are very different. It is evident that there is mutual covering amongst neighbouring threads, and that this leads to the inaccuracy of the black-and-white shading effect. There could be two reasons for mutual covering: it could be caused by common weaving points existing in the weave structure, or it could be caused by juxtaposed threads due to overlong floats. Since common weaving points have been avoided in the course of gamut weaves design, the sole reason for mutual covering is juxtaposed threads due to overlong floats. Thus, the longer the float, the better the covering effect.

Figure 5.10 shows three methods of increasing weaving points. When using weft-face gamut weaves to design a woven structure, the mutual covering of threads was caused mostly in the weft direction, i.e. there was mutual covering between weft threads. As a result, the covering effects of (b) and (d) in Fig. 5.10 are worse than that of (c).



5.10 Effects of adding interlacement points on weft-face weaves.
 (a) Original weave; (b) diagonal transition; (c) horizontal transition;
 (d) vertical transition.



5.11 Effects of reducing interlacement points on warp-face weaves.
 (a) Original weave; (b) diagonal transition; (c) horizontal transition;
 (d) vertical transition.

Table 5.1 Relationship between weave structures and black-and-white shadings

Character of gamut weaves	Black-and-white shading effect	
	Light areas	Dark areas
Diagonal transition	Satisfactory	Satisfactory
Horizontal transition	Worse	Best
Vertical transition	Best	Worse

Note: black warp and white weft.

Similarly, Fig. 5.11 illustrates another three methods of adding weaving points. When using warp-face gamut weaves (a reverse effect of Fig. 5.10) to design a woven structure, the mutual covering of threads was caused mostly in the warp direction, i.e. there was mutual covering between warp threads. In this case, the covering effects of (b) and (c) in Fig. 5.11 are worse than that of (d).

In brief, the lesser the mutual covering caused among threads in a fabric structure, the better the effect of black-and-white shading reproduced on the fabric. Table 5.1 shows the relationships between weave structures and black-and-white shading effects of designed fabric that coincide with the

results of actual design theory in practice. If the arrangement of threads is revised so that the warps become white and the wefts become black, the relationship between weave structures and the black-and-white shading effect of the designed fabric also needs to be reversed. Moreover, since the change of warp and weft density may also affect the covering effect of the fabric, the design of gamut weaves needs to be considered for the distribution of grey-scales in the digital image when processing a simulation design of colourless digital jacquard fabric.

5.7 Design of colourful digital jacquard fabrics

By using the layered-combination design mode for digital jacquard fabric, it is possible to produce jacquard fabric featuring a rich mixed colour effect by the combination of several single-layer structures. The colour expression of colourful digital jacquard fabric distinguishes itself from that of traditional jacquard fabric in two aspects: firstly, by the increased number of colours that can be produced (now at a mega level) and, secondly, the capability of expressing a multicoloured shading effect. As already mentioned, this study was carried out to explore the relevant relationships between structure design/combination methods and final fabric effects. Additionally, taking the smooth colour shading effect of digital jacquard fabric as an objective, an optimal structure design/combination method has been proposed. Thus, this study provides the essential technical references for the design creation of colourful digital jacquard fabric.

5.7.1 Choice of digital images

There is no particular limitation on the selection of image for colourful digital jacquard fabric design. A portrait image was selected as the optimal expression of colourful shading effects and structural characters due to the fine and smooth colour shading effect it portrays. As long as the simulative design of a portrait is satisfactory (in both the aspects of colour and pattern), the structural design method can be applied to other digital images.

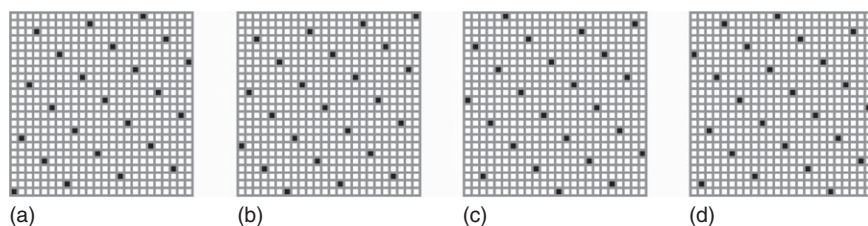
5.7.2 Selection of structure design methods

Multicoloured jacquard fabric must be designed with a complex compound weave structure. Traditional complex compound weave design was approached by the combination of simple weaves in single-weave design mode. However, in digital jacquard textile design, the combination of single-layer structures has replaced the design process of single complex weave design. According to the combination principle of fabric structure, neighbouring threads constructed in the woven structure produce only two basic

effects, viz. the juxtaposition effect (a non-backed structure effect) and the mutual covering effect (a backed structure effect). Therefore, the generation of a non-backed or backed effect after the weave combination needs to be thoroughly understood for the design of gamut weaves and the combination of single-layer fabric structures. In addition, since the combined effect of primary weaves may represent the combination of gamut weaves in the same weave-database, it can be concluded that, when combining two single-layer structures designed by backed effect weaves, the compound fabric structure will also exhibit a backed fabric effect. On the other hand, when two single-layer structures designed with non-backed effect weaves are combined, the compound fabric structure may show a partial backed fabric effect, i.e. both backed effect and non-backed effect appear on the face of the fabric at the same time. Figure 5.12 shows four primary weaves of 24-thread sateen designed by displacing the starting point of the original primary weave. It can be used to establish four weave-databases for further design practice.

5.7.3 Comparison of effects in fabrics

In terms of the design principle of the layered-combination design mode for digital jacquard textile, any colourful digital image can be separated into four grey layers (representing CMYK, respectively). If the four series of gamut weaves that are designed on the basis of the four primary weaves in Fig. 5.12 are applied to such four grey layers, to design single-layer structures, three combination methods are available to combine these four single-layer structures to form a compound one. The first method is the combination of the four single-layer structures designed with the same gamut weaves, used repeatedly four times. The resultant fabric effect is shown in Fig. 5.13 (a). The mutual covering effect amongst juxtaposed weft threads dominates the face effect of the fabric in which the weft threads with shorter float are covered by those with a longer float. The second method is the combination of four single-layer structures designed with two



5.12 Four primary weaves of 24-thread sateen. (a) Original primary weave; (b) 6 points moved; (c) 12 points moved; (d) 18 points moved.



(a)

(b)

(c)

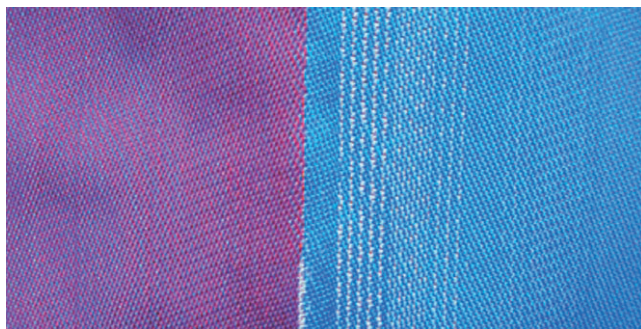
5.13 Fabric effects designed by different compound structures.

(a) Same gamut weaves; (b) pairing of gamut weaves; (c) four gamut weaves.

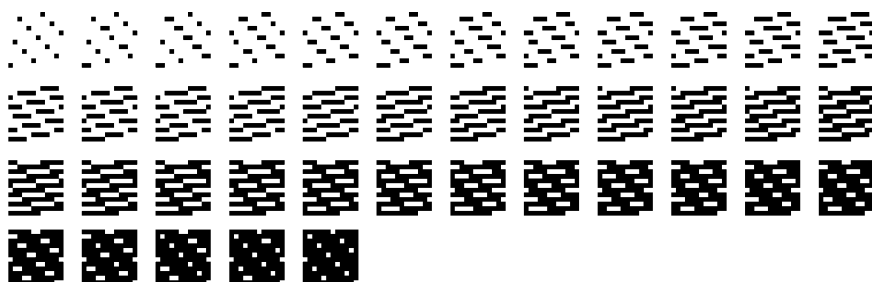
series of gamut weaves (pairing) which are used twice. The two series of gamut weaves in different weave-databases have the same original primary weave but have different weave starting points, i.e. the original primary weave and its starting point are shifted 12 points/threads. The fabric effect produced is shown in Fig. 5.13 (b) in which the mutual covering effect and no-covering effect are both shown on the face of the fabric, at the same time. Compared with the original digital image, the colour reproduction in the area of the no-covering structure effect is better than that in the area of the mutual covering structure effect. The third combination method is the combination of single-layer structures designed with the four series of gamut weaves which have the same original primary weave but different starting points, i.e. original primary weave, 6 points/threads shifted, 12 points/threads shifted, and 18 points/threads shifted. The resultant fabric effect is shown in Fig. 5.13 (c) in which the mutual covering effect and the no-covering effect are shown on the face of the fabric at the same time. Compared with the original digital image, the area of the no-covering structure effect seems to feature better colour reproduction than that in the area of the mutual covering structure effect. Further, during fabric production, a serious problem was generated, i.e. a regular slanting effect of weft threads. This phenomenon seriously affected production efficiency.

5.7.4 Design experiments and technical evaluation

In order to identify the reasons behind the colour deviations caused in simulative design of colourful digital jacquard fabric, further design practices were considered (see below), with the aim of reproducing the ideal effect of smooth colour shading of the digital image. The same gamut weaves method and the combination method of single-layer fabric



5.14 Broken streaks generated in the colour shading effect.

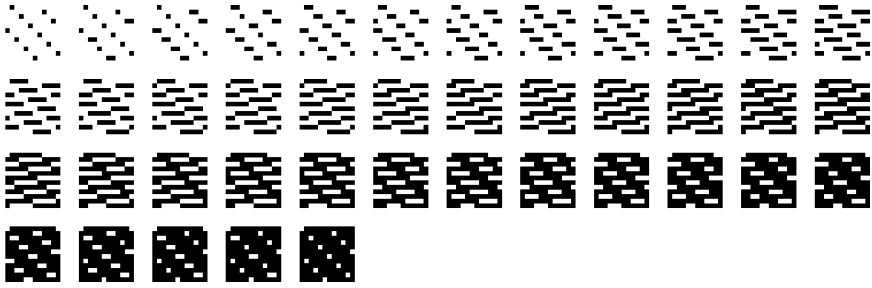


5.15 Effects of basic gamut weaves.

structures were applied, just as they were in Fig. 5.13 (b), i.e. the method consists of pairing gamut weaves and pairing weave-databases. In order to assess the fabric effects generated from compound fabric structures, the image selected for design practice had a smooth colour gradation. As a result, the fabric produced exhibited the defect of broken streaks (Fig. 5.14). Thus, it can be concluded that shortcomings in the structure design are the major reasons leading to the generation of the broken streaks which, in turn, caused the colour deviation in the simulative design of digital jacquard textile.

To identify the main reason for the broken streaks, experimental research was carried out to inspect the combination effect between two series of gamut weaves. Figure 5.15 shows the basic gamut weaves and Fig. 5.16 shows the joint gamut weaves designed by shifting six points from the original starting point. When using these two series of gamut weaves to design four single-layer fabric structures, the basic gamut weaves were applied twice to design two single-layer structures arranged in odd layers, while the joint gamut weaves were applied to two even layers.

After the combination of the four single-layer fabric structures, a compound fabric structure was formed in which two single-layer structures designed from basic gamut weaves were located in the odd layers (i.e. the

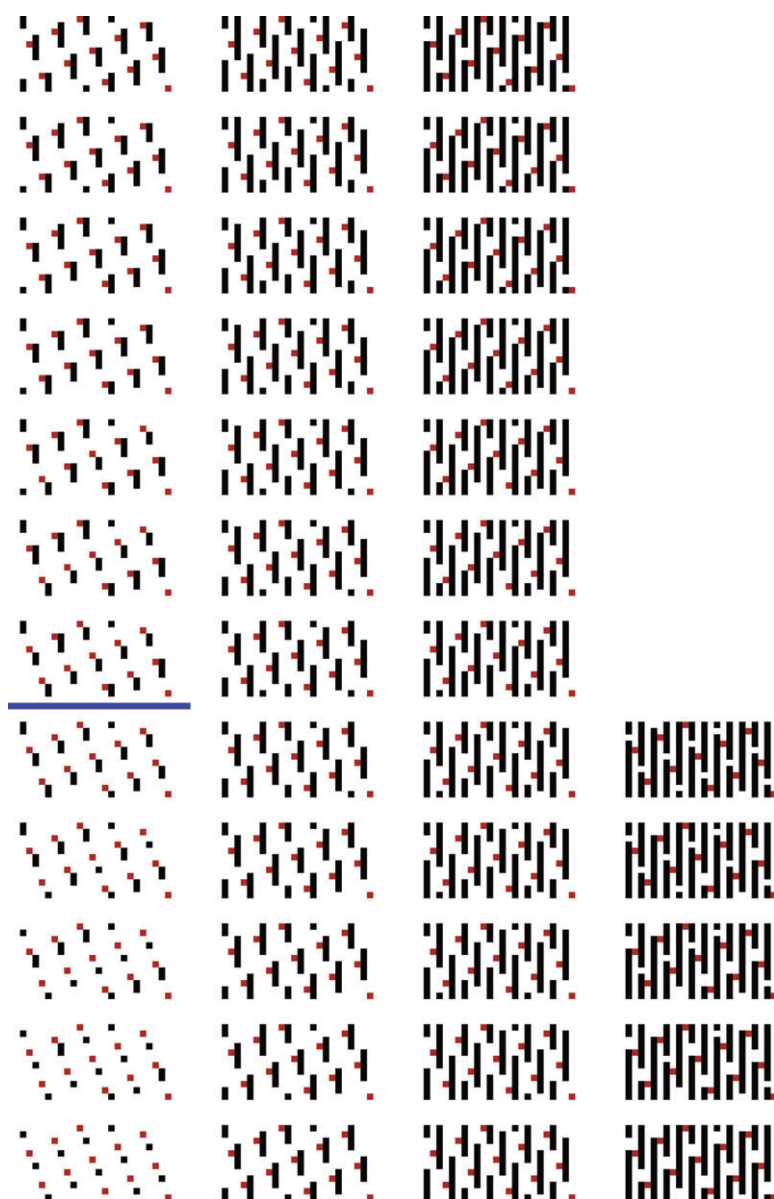


5.16 Effects of joint gamut weaves designed by shifting the starting points.

first and third layers), while another two single-layer structures designed from joint gamut weaves were located in the even layers (i.e. the second and fourth layers). In order to inspect the combination effect of the fabric produced, an experiment was carried out to ascertain the detailed effect of compound weaves combined from basic and joint gamut weaves. Figure 5.17 shows the combination effect of the first weave of basic gamut weaves and joint gamut weaves in a two-layer combination. Due to the use of the same combination method, i.e. the same starting point and same gamut weaves, the compound structure effect of this two-layer combination is similar to that of the four-layer combination. Careful examination discovered that the mutual covering effect and no-covering effect exist at the same time in compound weave effects. As shown in Fig. 5.17, the compound weaves before the mark (vertical line) show a non-backed compound effect while the compound weaves after the mark indicate a partial backed compound effect.

The results obtained from practical research into the combination of gamut weaves indicated that, when two series of gamut weaves are combined (and in which one series of the gamut weaves are designed by shifting the starting point of the other), the compound fabric structure shows both the mutual covering effect and a no-covering effect on the face of fabric at the same time.

In order to reduce or eliminate the broken streaks caused in compound fabric structures, further design experiments were conducted to investigate the main reasons that led to the generation of these broken streaks. Taking 12-thread satin as an example, 12 kinds of gamut weaves and weave-databases were created by changing the starting point and by different methods of adding interlacing points. The effects of gamut weaves are shown in Appendix 1, section A1.1, in which six kinds of gamut weaves/weave-databases, from N12-3w41-1 to N12-3w41-6, were designed by changing the starting points of primary weaves on the basis of gamut weaves N12-3w41. Two kinds of gamut weaves/weave-databases, N12-3w-z41 and










5.17 Combined effects of first basic gamut weave and joint gamut weaves.

N12-3w-z41-11, were designed by changing both the starting points of the primary weaves and the insert directions of the interlacing points, i.e. the insert direction of the interlacing points of N12-3w-z41 is left, while that of N12-3w-z41-11 is right. Two kinds of gamut weaves/weave-databases, N12-3w-z41-9 and C12-3w-z-y41-9, were paired. N12-3w-z41-9 was designed by changing the starting point of the primary weave and the insert direction of the interlacing points (similar to the design method of N12-3w-z41-11 described above). C12-3w-z-y41-9 was designed by changing the starting points of the primary weaves and the insert direction of the interlacing points (which was changed to right-left-right, in order to reduce the covering effect caused in the fabric structure).

As shown in Table 5.2, seven design experiments were conducted with the aim of reducing broken streaks, all with the same fabric technical specification of a four-layer combination but with different methods for gamut weaves design and for single-layer fabric structure combination. In the experiments A to D, the design methods for the gamut weaves were similar, i.e. same inset direction of interlacing points but different starting points. As a result, the combination effects of the single-layer fabric structures in the experiments were different. After weaving the sample, the broken streaks generated on the face of the fabrics of the four swatches were more pronounced, and the fabric effect was seriously affected. Furthermore, the position of the broken streaks on the fabric was random.

In experiment E, the insert directions of the interlacing points of the gamut weaves was changed to right and left, whereby the broken streaks caused on the face of the fabric were visibly reduced. In experiment F, the starting point was changed further, and the swatch produced had fewer broken streaks compared with the experimental swatches A to D, but more than that of experiment E. In experiment G, based on the design method of gamut weaves of experiment F, the insert direction of the interlacing points of gamut weaves was changed into right-left. The fabric effect thus produced resulted in only a few broken streaks. Figure 5.18 shows the partial fabric effects of most (serious), some (less serious) and few (light) broken streaks produced in the design experiments. Figure 5.18 (a) indicates the fabric effect with most broken streaks. It was found that the broken streaks in the partial area on the face of the fabric were connected; they appear to have formed a backed structure that led to a serious covering effect in the compound structure. Subsequently, the colouring effect of the jacquard fabric deviated more from the original image. Figure 5.18 (b) presents a fabric effect with some broken streaks. These broken streaks exhibited clearly on the face of the fabric and have a mild influence on the fabric structure, but a more pronounced colour effect. Figure 5.18 (c) shows the fabric with few broken streaks, and the fabric structure is less affected when compared to the colour effect of fabric; however, the colour shading effect between the two colours is still unsatisfactory.

Table 5.2 Results of design experiments to reduce broken streaks

Experiments	Gamut weaves and weave-databases	Insert direction of interlacing points (odd/even layers)	Diagram of combination method	Broken streaks/ colour influence
A	N12-3w41-1/N12-3w41/ N12-3w41-1/N12-3w41	Right		More/serious
B	N12-3w41-3/N12-3w41/ N12-3w41-3/N12-3w41	Right		More/serious
C	N12-3w41-2/N12-3w41/ N12-3w41-3/N12-3w41-1	Right		More/serious
D	N12-3w41-3/N12-3w41/ N12-3w41-5/N12-3w41-2	Right		More/serious
E	N12-3w-z41-11/N12-3w-z41/ N12-3w-z41-11/N12-3w-z41	Left/right		Few/light
F	N12-3w-z41-9/N12-3w-z41/ N12-3w-z41-9/N12-3w-z41	Left/right		Some/medium
G	C12-3w-z-y41-9/N12-3w-z41/ C12-3w-z-y41-9/N12-3w-z41	Left/right-left		Few/light

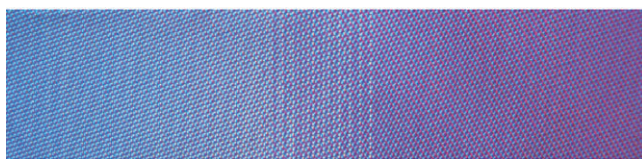
Note: gamut weaves and weave-databases are presented in Appendix 1.



(a)



(b)

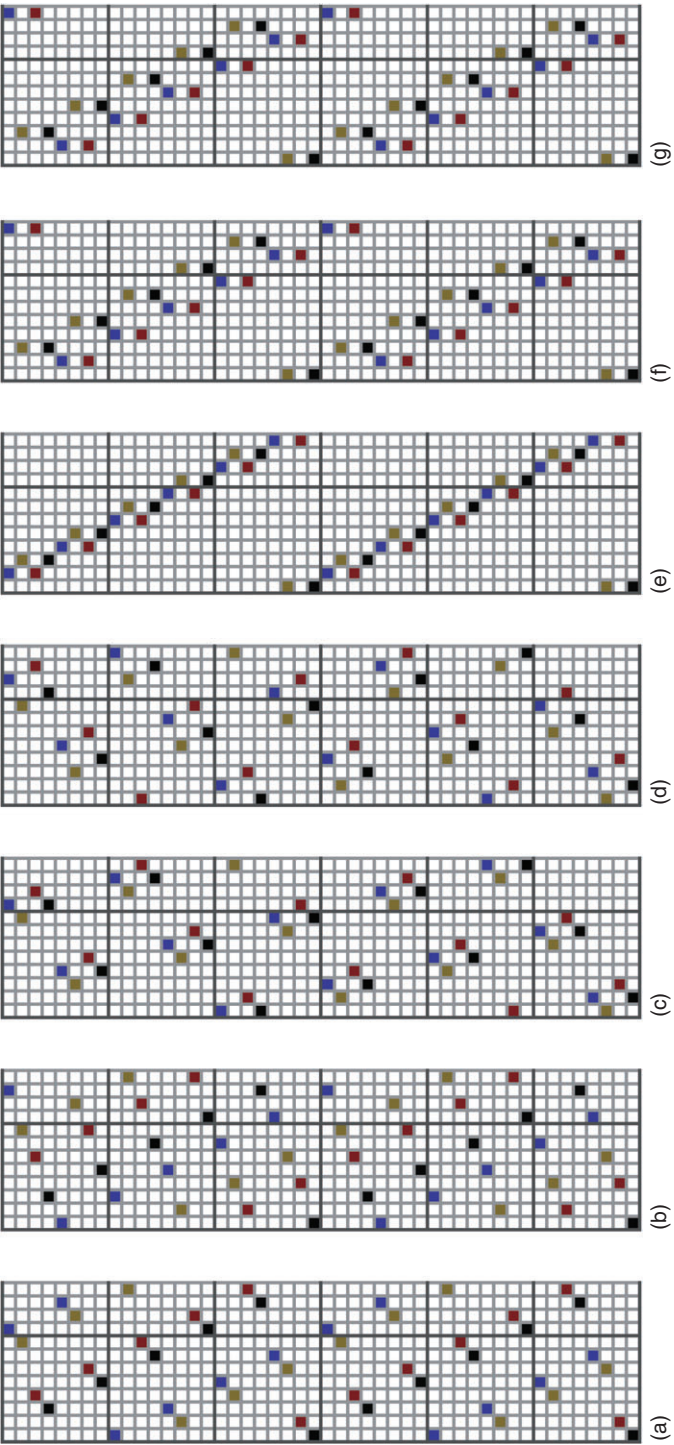


(c)

5.18 Fabric effects of broken streaks generated in the design experiments. (a) Most (serious); (b) some (less serious); (c) few (light).

Additionally, it was found that the broken streaks generated on the face of the fabrics were distributed randomly, and the position of the broken streaks varied with the change of design methods of the gamut weaves and the combination methods of the single-layer fabric structure. As shown in Fig. 5.18, the broken streaks of the three fabric swatches designed by the three methods were distributed differently on the face of the fabric. To help identify the major reason for the broken streaks, the combination effects of the four primary weaves of the four series of gamut weaves in the seven design experiments, from (a) to (g), are presented in Fig. 5.19. Obviously, the combination effect of primary weaves can affect the woven texture of jacquard fabric. However, through the change of combination method of the single-layer fabric structure, the generation of broken streaks can be reduced, though not removed completely.

Since all the broken streaks were located at the junction area between the covering and no-covering effect of compound weave structures, it is implied that the proportion of backed structures and non-backed structures would vary when the single-layer structures designed by different gamut weaves and with different combination methods were combined. Figure 5.20 shows the combination effect of the first weave of basic gamut weaves and the entire joint gamut weaves in design experiment E. In comparison with the results in Fig. 5.17 (that was combined by the first weave of the



5.19 Combined effects of four primary weaves of four series of gamut weaves.

basic gamut weave and all the joint gamut weaves in design experiment B), the non-backed compound weaves before the vertical mark in Fig. 5.20 are more than those in Fig. 5.17. In addition, the backed effect of the compound structure in Fig. 5.20 is actually more of a half-backed effect, i.e. neighbouring threads cover only one side while the other side exhibits a non-backed effect. As a result, the compound structure shown in Fig. 5.20 is steadier than that of Fig. 5.17.

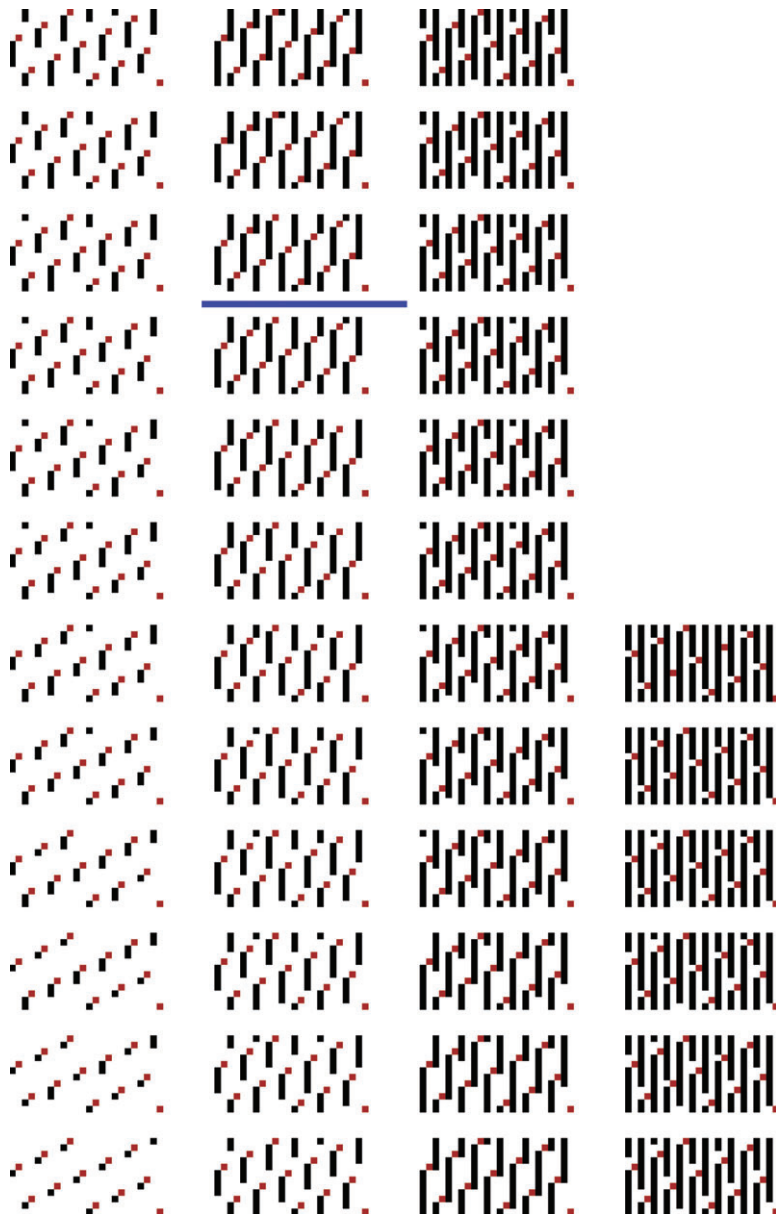
Based on the results of the design experiments stated in Table 5.2 and the related technical analysis, the conclusion can be drawn that the broken streaks exhibited on the face of the fabric in digital colourful jacquard fabric design has to do with the design method of the gamut weaves. When applying gamut weaves created by a normal design method to design a single-layer fabric structure, the broken streaks cannot be eliminated on the face of the fabric after combination. By changing the insert direction of the interlacing points during gamut weave design, the generation of broken streaks can be reduced, but they cannot be avoided completely. It could be argued that the design experiments were conducted only with a simple colour shading effect as the sole and optimal method for verifying the broken streaks caused in digital colourful jacquard fabric design under a layered-combination design mode. When designing fabric with complex images, because of the richer and more staggered mixed colours on the face of the fabric, broken streaks may be avoided.

5.7.5 Design practice with full-colour compound structures

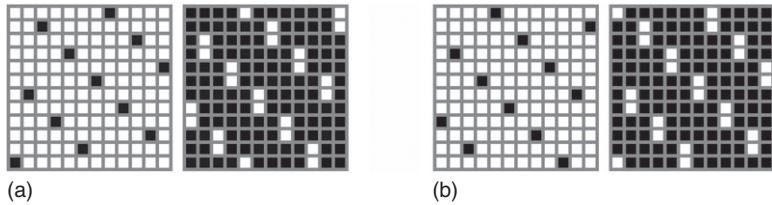
Compared with the original digital image, the colour effect of a jacquard fabric produced will deviate due to the existence of broken streaks caused by mutual covering effects in a compound fabric structure. However, since more colour deviation was produced in the area dominated by a backed structure, and less so in the area dominated by the non-backed structure, if mutual covering effects amongst juxtaposed threads can be avoided during the design process of compound fabric structures, the simulative design of colourful digital jacquard fabric should be able to be realised. In fact, the design method for a full-colour compound structure offers the capability of designing a non-backed and full-colour compound structure. In theory, it meets the requirements of simulation design of colourful digital jacquard fabric.

Design of full-colour weaves

Taking 12-thread satin as an example, and based on experiment G in Table 5.2, full-colour technical points were setup for a basic primary weave and a joint primary weave, respectively, in accordance with the design principles and methods of a full-colour compound structure. The position of



5.20 Combined effects of first basic gamut weaves and joint gamut weaves.



5.21 Primary weaves and their full-colour points. (a) Basic primary weave; (b) joint primary weave.

technical points is shown in Fig. 5.21. The basic gamut weaves produced were Ac12-3w-z-y41, while the joint gamut weaves were Ac12-3w-z-y41-9 (see panel (o) Appendix 1, section A1.1). Two series of gamut weaves have the same technical parameters, i.e. adding points once is 3, insert direction is right-left or left-right, weft-wise, and the number of gamut weaves for each is 37.

Design practice of full-colour shading

The differences in fabric effects between digital jacquard and traditional jacquard fabric relate to the substantial increase of mixed colour numbers and the capability of expressing a print-like colour shading effect. Therefore, the major challenge is to design and produce a kind of colour palette with full-colour changing effects similar to that of a spectrum colour effect. The superior design effect of digital jacquard fabric *per se* is a fine illustration of the superiority of digital jacquard fabrics over those designed and produced by the traditional plane design method.

By using basic and joint gamut weaves alternately to design single-layer fabric structures, the completed compound fabric structure, in which the odd number layers were designed by basic gamut weaves while the even number layers were designed by joint gamut weaves after combination, has made possible a smooth colour shading effect on the face of jacquard fabrics without broken streaks. Figure 5.22 shows the fabric effect of a full-colour shading palette designed with four primary colours, viz. three basic coloured threads (cyan, magenta and yellow), and one black thread. Following the design method of a four-layer full-colour compound structure, a full-colour shading palette with three primary colours was realised, to which black can be applied to adjust colour brightness. The structure design method started by designating two primary weaves. The full-colour points were designed first, then basic and joint gamut weaves were designed, respectively, on the basis of the two primary weaves. Finally, basic and joint gamut weaves were applied alternately to design four single-layer fabric structures. Basic gamut weaves were used for the odd numbered fabric



5.22 Effect of smooth colour shading with full-colour effect.

structural design, while joint gamut weaves were used to design the even numbered fabric structures. After combining the four single-layer fabric structures, in an order of 1 : 1 : 1 : 1, the compound fabric structure obtained was capable of expressing a full colour shading effect. Even if the colours of the threads were changed, the colour shading effect remained unchanged in the compound fabric structure. Therefore, designing a full-colour compound structure under the layered-combination design mode met the technical requirements of designing digital jacquard fabric with a full-colour shading effect. Indeed, this design mode enabled digital jacquard fabric to be produced with a print-like colour effect that was impossible to attain under the traditional plane design mode. Section A3.1 in Appendix 3 shows more creations with a full-colour shading effect.

5.7.6 Summary

Through design experiments on colourful digital jacquard fabric, especially those on fabric structure, the major reason for generating broken streaks was identified and an optimal solution was found. The results suggested that the design methods of gamut weaves and the combination methods of single-layer fabric structures have laid the foundation for colourful digital jacquard fabric design and production. The compound structure of jacquard fabric combined with gamut weaves designed by the normal method has the capability of expressing a mega level of mixed colours on the face of the fabric. However, broken streaks cannot be avoided during the design process. When the full-colour compound structure design method is used, through the setting of full-colour technical points on the gamut weaves, the digital jacquard fabrics produced were capable of expressing fine colour shading and accurate colouring effects. For these reasons, when approaching a design creation with the aim of attaining the true-to-original effect of a digital image, the full-colour compound structure is the optimal choice. When designing digital jacquard fabric to show innovative effects, both half non-backed and non-backed compound structures are capable of expressing the unique woven effect of jacquard fabric that cannot be

Table 5.3 Findings of design practices for colourful digital jacquard textiles

Broken streaks/ colour influence	Effect of compound structure	Corresponding experiments	Recommended design application
More/serious Some/medium	Forming backed area Individual broken streaks	A–D F	Unfavourable Unfavourable
Few/light None/none	Half-backed structure Non-backed	E and G Full-colour shading	Innovative effect Simulative or innovative effect

imitated by any other means of art. Gamut weaves designed by the normal method are regarded as unsuitable for design creations with either simulative or innovative effects, due to the generation of too many broken streaks in the compound fabric structure.

Table 5.3 summarises the findings of design practices for colourful digital jacquard textiles.

5.8 Conclusion

This chapter has presented the most important part of our research into digital jacquard textile design. Since the layered-combination design mode is an original contribution to the design of digital jacquard textiles, the technical problems discovered in the design experiments are unprecedented. These problems relate to colourless and colourful digital jacquard textile design, such as the balanced interlacement required in fabric production and the broken streaks caused in compound structures. Through a series of experimental research and analysis of the results, the key innovation points of digital jacquard textile design pertaining to the design of colour and structure, as well as the relationship of fabric structure design and its colour expression, have been identified. In addition, the design concept, design principles and design methods proposed in the theoretical research have proved to be of tremendous benefit to the innovation of jacquard textile design. The results obtained from both experimental research in this chapter and the theoretical research in Chapter 3 have laid a solid foundation for the design creations of creative digital jacquard fabrics under the layered-combination design mode.

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Digital design of novel simulative effects in jacquard textiles

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Abstract: This chapter introduces design creations made in simulative digital jacquard fabric under the layered-combination design mode, as well as proper design illustrations created in both black-and-white and colourful simulative digital jacquard fabrics.

Key words: simulative, digital, jacquard, woven, fabric, layered-combination, colour.

6.1 Introduction

Simulative jacquard fabric, which seeks to imitate images within the fabric, is one of the most important varieties of jacquard textiles. The design of true-to-original simulative jacquard fabric under the traditional plane design mode required the highest levels of skills and technique due to the complex design processes and complicated fabric construction involved. The digital layer-combination design mode, however, especially the development of the full-colour compound structure design method proposed in this book, has overcome the restrictions of the traditional single-plane design mode. Thus, the simulative design of digital jacquard fabric can now be approached in an efficient and convenient manner.

The simulative design of jacquard fabric can be broadly divided into two types: black-and-white simulative effect and colourful simulative effect. In this chapter, based on the application of the layered-combination design mode, the innovative design methods of true-to-original simulative jacquard fabrics, with both black-and-white and colourful simulative effects, are introduced from basic design to variant design method. As a result, the merits of designing digital jacquard textiles in the layered-combination design mode have been reinforced.

6.2 Design of black-and-white simulative effect fabrics

Simulative fabric refers to a fabric whose visual effects, such as pattern and colour, are capable of imitating given images. In this section, innovative

design methods for black-and-white simulative fabric using the layered-combination design mode are presented. The main design problems during structural design are identified and solved.

6.2.1 Background

Ancient China and medieval Europe were two major regions where advanced jacquard techniques and jacquard fabric products developed quickly. A wealth of literature documenting black-and-white simulative fabric and related design methods can be found. In Europe, black-and-white simulative fabric was produced with a single-layer fabric structure in cotton or linen, often with a rather coarse fabric effect. However, in ancient China black-and-white simulative fabric was normally a silk product featuring elaborate patterns and colour effects. It was constructed with a two-weft backed structure with threads of pure silk, and given the name *Xiangjing* (Wang, 2002a; 2002b) – a fabric with simulated portraits and landscape motifs.

The structural design of traditional black-and-white simulative fabrics was approached manually in both China and Europe. The fabric structure was drawn in detail on point paper: it was a time-consuming task. For example, at least six months were needed to draw the fabric structure of an achromatic portrait or landscape painting on point paper. Although there are disadvantages in the traditional manual design method of jacquard fabric, its convenience in changing fabric structure when designing the structure of shading pays off: the designer is free to reduce or add interlacing points in any spot on the point paper to meet the technical requirements of balanced interlacement. As a result, the jacquard fabric created exhibits fine black-and-white shading effects with satisfactory grey-scales, albeit produced by a time-consuming and often laborious manual process.

With the development of digital design and production technologies, new opportunities arose to improve simulative fabric. Computer-aided design (CAD) of black-and-white simulative fabric became popular and design efficiency was enhanced. A single-layer structure was used as the foundation: hand drawing on point paper was replaced by computer-assisted design processing (Neudeck and Zschenderlein, 2006). Yet, since the structural design principle remained unchanged, the computer-assisted method was not able to adjust the interlacing points of shaded structures as freely as the manual process (Zhou and Wang, 2001c). The inter-covering effect caused by mutual slippage among the juxtaposed threads could not be controlled efficiently. As a result, the middle gradations of grey-scales in the fabric were affected greatly: if a digital image presented rich gradations, great disparity existed between the actual fabric effect and the original digital image.

6.2.2 Basic design concepts

Structural design is the key to black-and-white simulative fabric design. To produce black-and-white simulative fabric, the design of shaded weaves is indispensable. Amongst the various shaded weaves, single-layer shaded weaves are the simplest. They are designed on the basis of satin or twill weave and feature weave transition effects, moving gradually from the warp face to the weft face, or *vice versa*. There are three main transition directions of shaded weaves: vertical, horizontal and diagonal transition. When designing simulative jacquard fabric manually, it is easy to adjust the interlacing points on point paper by the integration of the three transition directions of shaded weaves so that the inter-covering among juxtaposed threads can be avoided. When designed with the aid of a computer, however, the weaving points of the fabric structure cannot be modified. The replacement between pattern colours and weaves is processed automatically from a fixed starting point by computer, i.e. the black-and-white shading effect cannot be adjusted by arbitrary addition or reduction of weaving points. As a result, even if the objective pattern and gradation of grey-scales are the same, the final fabric effect with a single-layer structure differs from the original image due to mutual extrusion and covering among juxtaposed threads.

Traditional Chinese black-and-white simulative fabric, *Xiangjing*, was a kind of jacquard fabric constructed with a weft-backed structure. It consisted of one white warp thread and two weft threads (black and white). The white warp thread and the white weft thread construct with plain weave, while the white warp thread and the black weft thread interweave to form a shaded weave structure. The black-and-white shading effect was designed by reducing the weave repeat and changing weaving points on the basis of satin primary weave, i.e. using plain weave as the balance point to design warp-face and weft-face shaded weaves, respectively. In order to meet the technical requirement of balanced interlacement of fabric construction, the *Bangdao* device (Zhou, 1988), a kind of warp lifting device (whose working principle is the same as that of a heddle frame in a dobby machine), and *Bangdao* weave (Zhejiang Institute of Silk and Textiles, 1987; 2002) were employed when black weft was woven into plain weave. As a result, plain weave could be replaced by *Bangdao* weave and the weave repeat was enlarged. By such a method, it was easy to adjust the interlacement balance at any point of the fabric structure through hand drawing of shading. Thus, any pattern could be applied to the design of black-and-white simulative jacquard fabric.

Such a design method was time-consuming and only available in manual design mode. It could not be used by computer programmed processing.

Moreover, at present, digital jacquard machines are no longer installed with the configuration of 'one harness corresponding to two ends'. Thus, the *Bangdao* device cannot be employed in digital production processing and, for this reason, the traditional Chinese black-and-white simulative jacquard fabric design method has lost its popularity over time. A new design principle and method to revitalise this traditional jacquard fabric effect is required.

6.3 Design principles and methods for single-layer and compound structures

In this study, innovation in the design of black-and-white simulative jacquard fabric, using the application of digital design and production technology, has taken two directions: designs using a single-layer structure and those using a compound structure. The former method is to design black-and-white fabric by tailor-made gamut weaves based on a colourless design mode and single-layer structure. The fabric structure is designed according to the varied brightness of the grey-scales within the digital grey image. The latter method is to produce an uncovered fabric structure with the support of proper accessorial threads based on the colourful design mode and compound fabric structure.

6.3.1 Design principles and methods for single-layer structures

The colourless design mode of the layer-combination design mode can be directly applied to develop black-and-white simulative fabric with a single-layer structure. It shares the same common design principles and methods as those described in the theoretical and practical sections of this book.

Colour design principles

The pattern design of black-and-white simulative fabric can now be achieved by using a CAD system. With this method, the pattern resolution is finer than that of traditional hand-drawn fabric design. In addition, the number of greys applied to the pattern design can be as high as 256. Given that the human eye can distinguish only a maximum of 64 shades of grey in a monochromatic scale (Zhou, 2002b), the greyscale of the digital image should be either equal to or more than this number if the design wants to imitate a true-to-original effect in a colourless jacquard fabric. Any eight-bit digital grey image that shows a maximum of 256 grades of grey can fulfill the design requirements for a black-and-white simulative fabric.

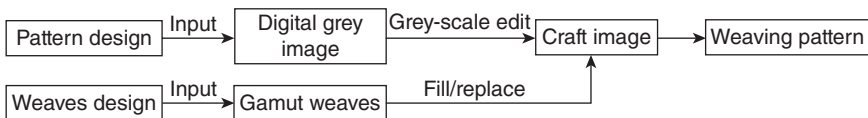
Structural design principles

Structural design is one of the most important steps during the design process for a black-and-white simulative fabric. It consists of the weave design and also the fabric structure design. The weave design should be approached from an image with a range of less than 256 greys to form shaded gamut weaves based on the detailed technical specification of the desired fabric. In general, there are three methods of adding interlacing points that are utilised to design shaded gamut weaves on selected primary weaves: vertical (warp-wise), horizontal (weft-wise) and diagonal transitions. However, due to the restrictions of balanced interlacement and mutual covering effect after production, the design of shaded gamut weave cannot be approached mechanically (Zhou and Ng, 2006d), as it frequently needs to be varied along with changes in the technical parameters of the desired fabric and the nature of the applied image.

Design methods and processes

The design and production of black-and-white simulative fabric in the colourless mode is based on the application of a jacquard CAD system and an electronic jacquard machine. The working route is described in Chapter 2 (see Fig. 2.2). During fabric production, an advanced weaving loom is used together with an electronic jacquard machine. Black-and-white simulative fabric designed with a single layer structure is interlaced by one series of warp and one series of weft threads so that the design of the fabric structure is correspondingly regular. The major design input during this process is the image and weave design in the jacquard textile CAD system. The series of tasks carried out are specified in Fig. 6.1 (Ng and Zhou, 2006).

In fabric design, the first step is pattern design. The pattern could be a hand-drawn artwork and/or a photographic one. The pattern is scanned and saved in a digital bitmap format. According to the weaving parameters of the fabric, the digital grey image is then revised using the editing tools offered in the jacquard textile CAD system, forming a craft image with the required range of greys and the proper technical parameters. At the same time, the weave design is tackled with the aid of the computer to form a series of gamut weaves that meet the requirements for production of the fabric. They are further applied to replace each of the corresponding greys



6.1 Design processes for black-and-white simulative fabric.

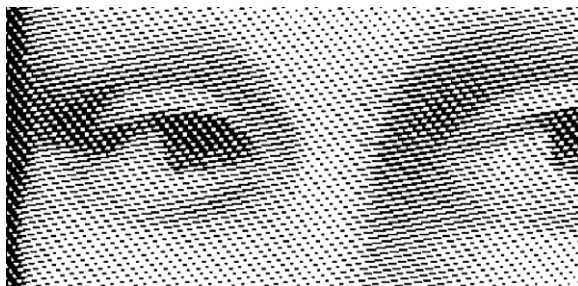
in the colourless image under a fixed starting point. As a result, the output is a weaving pattern that consists of weaving data (see Fig. 6.2), i.e. only either raiser points or sinker points in a thread. This provides the foundation for further production of black-and-white simulative fabric. In addition, since the colours of black-and-white simulative fabric are translated by changing either the warp or the weft thread, black-and-white simulative fabric designed by the digital jacquard technique can be used to develop a series of products with the same weaving pattern but with different monochromatic effects.

6.3.2 Design principles and methods for compound structures

The design principles and methods of black-and-white simulative fabric with a compound structure are different from those of the design method of a single-layer structure, and are based on a new design concept devised from the layered-combination design mode.

Design principles

Since the design method of traditional Chinese black-and-white simulative fabric, i.e. *Xiangjin*, cannot be approached in a digital design manner, design methods for black-and-white simulative jacquard fabric are mostly devised from the single-layer structural design method. Although design efficiency has been improved, the outstanding issue of mutual covering among juxtaposed threads has not yet been overcome. When designing digital jacquard fabric for black-and-white simulation using a digital image directly, the final fabric effect is unsatisfactory because the black-and-white shading effect cannot be reproduced accurately. For this reason, in this study, an innovative design method has been introduced, integrating a single-layer structure and a backed structure to address the structure-based technical problems. The basic design principle is to add a supplementary thread between the two



6.2 Weaving pattern of black-and-white simulative fabric.

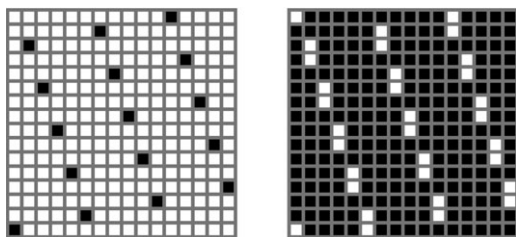
adjacent threads of a single-layer structure. By doing so, the mutual covering among colouring/floating threads arranged in juxtaposition can be avoided. Details are as follows:

- (i) The fabric is constructed by two series of threads arranged in juxtaposition and one series of threads in another direction. One group of juxtaposed threads is used as colouring/figuring threads, whereas the other group of juxtaposed threads is applied to form a compound fabric structure as joint threads. The latter serves as a supplementary thread and functions to prevent the colouring threads from slipping and covering one another. The joint threads are not visible from the face side. Theoretically, colouring thread can be deployed both warp-wise and weft-wise; however, weft-wise is preferred for a better balanced interlacement of the fabric structure.
- (ii) Colouring threads are capable of expressing figured effects with smooth black-and-white shading through the deployment of shaded gamut weaves similar to that of a single-layer fabric structure. The weave structure of supplementary threads is designed following the design principle of a full-colour compound structure. Due to the existence of supplementary threads, the colouring threads will not move and are covered by each other.
- (iii) For colour consideration, the colouring threads should employ black or a dark colour while the supplementary threads should be of the same colour as the threads interwoven in the other direction (white or light colours). In addition, in order to reduce the colour influence on the figuring effect, the supplementary threads should preferably be finer than the colouring threads.

Design methods

The structure design of a black-and-white simulative fabric with a compound structure involves three parts: the primary weave design, the gamut weaves design of figuring threads, and the weave design of supplementary threads. The primary weave design is the same as that of a full-colour compound structure design, and involves the selection of primary weave and the design of full-colour technical points on primary weaves. Taking 16-thread satin as an example (see Fig. 6.3), the primary weave is designed with a 16-thread five-step weft-face sateen, whose valid full-colour technical points are 16-thread 13-step warp-face satin.

Based on the primary weave and its full-colour technical points, the design of gamut shaded weaves can be approached as shown in Fig. 6.4. Interlacing points are added gradually along the weft. When the enhancement number of shaded interlacing points (M) is equal to the weave repeat (R), the number of basic weaves is at a minimum $R - 1$; when $M = 1$, the number of basic weaves is the maximum $R(R - 2) + 1$.



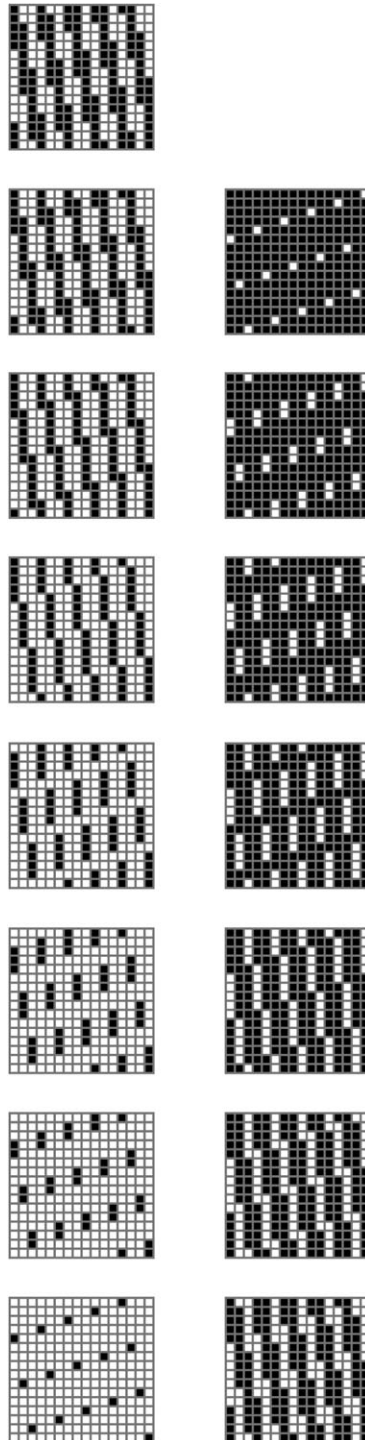
6.3 Primary weave and its full-colour points.

The approach to the joint weave design for supplementary thread is based on full-colour technical points. Without destroying the full-colour points, the joint weave is designed by regular variation. Full-colour points can also be applied as joint weave directly. Fig. 6.5 illustrates three basic design methods. Weave (a) is designed by directly transferring from full-colour points; weave (b) is designed through adding weaving points continuously on a basis of full-colour points; and weave (c) is designed by adding weaving points discontinuously on a basis of full-colour points. In fact, with different joint weaves, the tightness of woven fabric can be adjusted by compound structures. For a combination method of fabric structure, the combination proportion is 1 : 1 across weft between colouring thread and the supplementary thread. Figure 6.6 shows the combined structure effect between the basic gamut weaves of Fig. 6.4 and joint non-backed weave (a) in Fig. 6.5. Due to the application of supplementary threads and a corresponding full-colour structure, the adjacent figuring threads arranged in juxtaposition cannot be covered by each other, and the entire weave variations are coloured on the face of the fabric. This enables jacquard fabric to express the black-and-white shading of grey-scales accurately, and thus a true-to-original simulated effect of black-and-white fabric can be achieved.

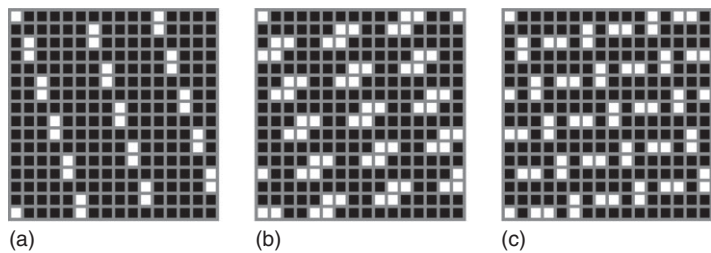
The key to black-and-white simulative design with compound structure lies in the innovation of fabric structure design. By merging the characteristics of the traditional manual design method with the application of digital design technology, the innovative structural design method introduced in this book is capable of accurately producing black-and-white simulative fabrics. It is envisaged that such technical advancement will have a tremendous potential in commercial applications.

6.4 Design illustrations for single-layer and compound structures

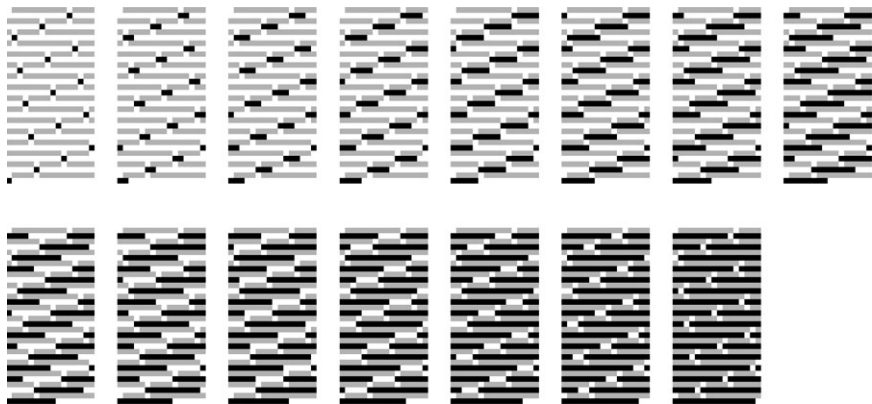
Design illustrations of black-and-white simulative fabrics with both a single-layer fabric structure and with a compound fabric structure are



6.4 Basic gamut weaves design based on primary weave.



6.5 Three types of joint non-backed weaves.



6.6 Combined effects of basic gamut weaves and joint non-backed weave.

introduced here to expound the design principles and design methods described above.

6.4.1 Design illustration for single-layer structures

The design of simulative effect black-and-white jacquard fabric with a single-layer fabric structure is the basic method used in digital jacquard fabric design. Based on the design method introduced above, the design creation of simulated effect fabric is approached efficiently by using only one series of warp thread and one series of weft thread, with tailor-made digital gamut weaves. Its simulated effects adequately achieve the reproduction of a given image.

Technical specification

The key technical parameters of this fabric are detailed in the technical specification table (Table 6.1). Due to restrictions on the technical

Table 6.1 Technical specification of black-and-white simulative fabric with single-layer fabric structure

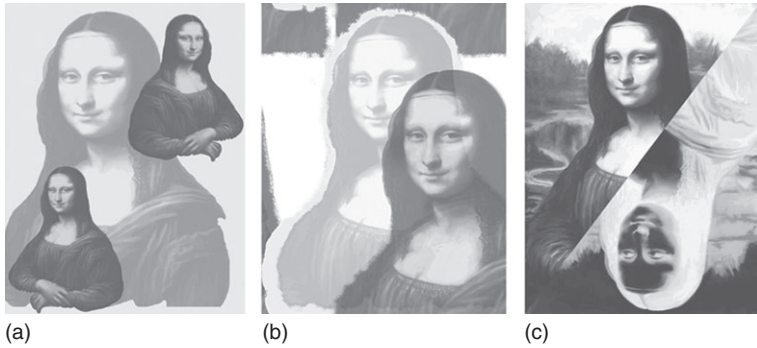
Parameters	
Materials	
Warp	1/166.7 dtex polyester (white)
Weft	1/166.7 dtex polyester (dark/dark/light/light)
Density	
Warp	45 threads/cm
Weft	60 threads/cm
Composition	Polyester 100%
Weave structure	12-thread gamut weaves, 41 grey grades
Design repeat	1248 needles \times 1680 fillings
Pattern repeat	22.01 cm (width) \times 28.07 cm (length)
Weight	238 g/m ²

conditions in fabric making, the parameters based on production devices for black-and-white simulative fabric cannot be modified during the design process. According to the key technical parameters shown in Table 6.1, the final fabric was designed by using 12-thread gamut weaves with lower fabric density. Polyester threads were employed in both warp and weft direction to facilitate ease of production. In addition, since the design of jacquard fabric with a portrait image always has the highest technical requirements for simulative effect, a portrait image was selected for the design creation of black-and-white simulative fabric.

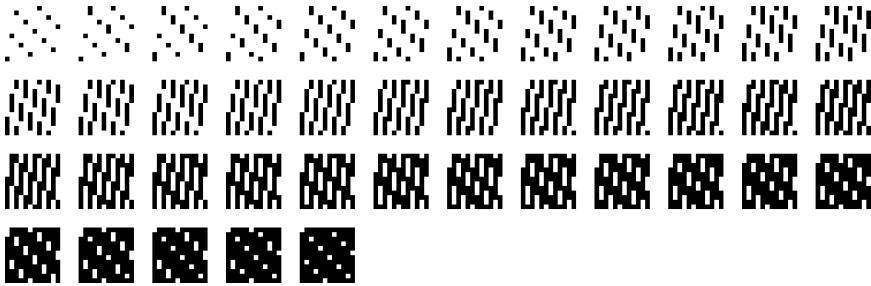
Design processes

The design of a black-and-white simulative fabric was approached on the basis of fabric specification and with the aid of a computer system. The design processes consisted mainly of image design and structure design. In accordance with the fabric parameters and the design principles and methods of colourless digital fabric, the digital images were designed with less than 41 grey-scales. Grey images of the same size are shown in Fig. 6.7. Grey image (a) is composed of two figures with contrast in both brightness and size; grey image (b) is composed of a figure in repetition and with contrast in brightness; and grey image (c) is composed of a figure in both its positive and negative forms.

Given the fact that the same gamut weaves can be used for any digital image with the same fabric technical parameters, only one series of gamut weaves needed to be created in line with the basic technical requirement of having a primary weave being 12-thread satin and with 41 grey grades of gamut weaves. In addition, since the fabric employed white warp threads



6.7 Digital grey images for simulative design with single-layer structure. (a) Superimposition of grey images; (b) overlapping of translucent grey images; (c) positive and negative grey images.

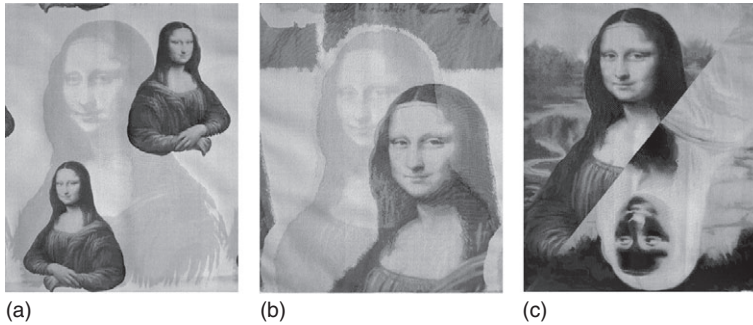


6.8 Gamut weaves for simulative design with single-layer structure.

and black weft threads, vertical transition was applied for the gamut weaves design in order to obtain a fine black-and-white shading effect in the dark areas of the portrait image. The gamut weaves designed are shown in Fig. 6.8.

Fabric effect

The black-and-white simulative fabrics produced are shown in Fig. 6.9. In comparison with the original grey image, the simulated effect of the final fabrics is considered satisfactory, though the colourful shading effect in the light area is still defective. Given the design illustrations above, there is no doubt that the single-layer structure designed according to the design method of a digital colourless mode benefits the design creation of black-and-white simulative fabric very well. Moreover, if the major fabric technical parameters remain unchanged, the same gamut weaves can be used for designing black-and-white simulative fabrics with different grey images. The



6.9 Fabric effects of simulative design with single-layer structure.

major properties of the fabric, such as the handle and thickness, will also remain unchanged.

Simulative design of black-and-white fabric suffers from the disadvantages of serious covering problems among threads due to the restriction of the single-layer fabric structure when gamut weaves with a larger weave-repeat and higher thread density are deployed. Thus, using a design method with a single-layer fabric structure is preferred for designing simulative effect fabrics with lower thread density and smaller weave-repeat gamut weaves.

6.4.2 Design illustration for compound structures

The simulative design of black-and-white jacquard fabric with compound fabric structure serves as a variant design. The compound fabric structure, originally based on a single-layer fabric structure, can be produced by adding supplementary threads between two adjacent colouring threads. The figuring threads on the face of a fabric feature a non-covering (full-colour) effect. With such a compound structure, smooth black-and-white shading can be achieved for simulative designs.

Technical specification

The key technical parameters of the fabric are shown in Table 6.2. As for the design with a single-layer fabric structure, based on valid technical parameters, there is no restriction for the image used for simulative design of black-and-white fabric. Table 6.2 reveals higher thread density in the final fabric than that designed with a single-layer fabric structure. Two silk threads were employed in the weft direction. One weft served as a figuring thread that had a contrasting colour to the warp thread, while the other served as a supplementary thread with a similar colour to that of the

Table 6.2 Technical specification of black-and-white simulative fabric with compound fabric structure

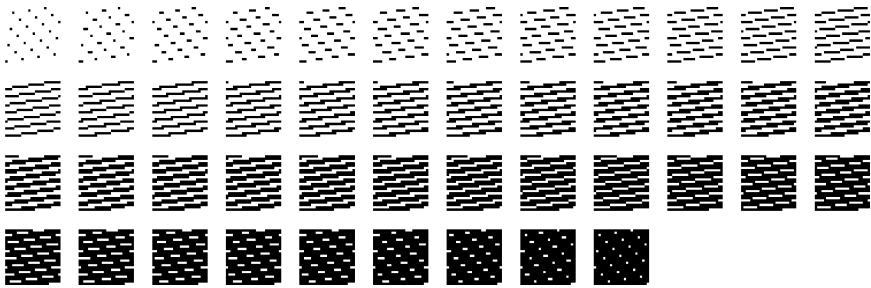
Parameters	
Materials	
Warp	22.2/24.4 dtex \times 2 silk (white)
Weft	22.2/24.4 dtex \times 5 silk (black)
	22.2/24.4 dtex \times 2 silk (white)
Density	
Warp	115 threads/cm
Weft	(45 + 45) threads/cm
Composition	Pure silk 100%
Weave structure	24-thread gamut weaves, 45 grey grades
Design repeat	12 000 needles \times 3744 fillings
Pattern repeat	104.3 cm (width) \times 41.6 cm (length)
Weight	139.9 g/m ²

**6.10** Digital grey-scale image for simulative design with compound structure.

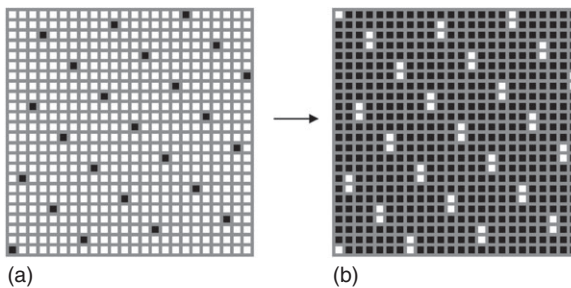
warp thread. In order to reduce the colour influence by the supplementary threads, the figuring thread is 2.5 times thicker than the supplementary thread. Moreover, in order to achieve higher thread density, larger repeat gamut weaves, i.e. 24-thread weaves, were applied, which doubled those used for the design with a single-layer structure.

Design processes

Since there is no restriction in the selection of a digital image for simulative design of black-and-white effect fabrics with a compound structure, the key to design lies in the structure design. A landscape image of 12 000 pixels \times 3744 pixels and 45 grey-scales (including black and white) was selected (Fig. 6.10). A series of gamut weaves of 24-thread weave and 45 grade shaded weaves was designed (Fig. 6.11). The enhanced number of interlacing points



6.11 Gamut weaves designed for figuring thread.



6.12 Design of joint non-backed weaves. (a) Primary weave; (b) joint weave.

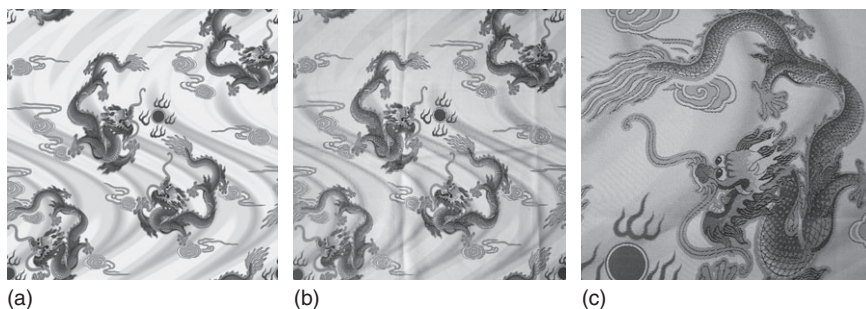
was 12, between 2 gamut weaves, and a horizontal transition direction was used for the gamut weaves design. The structure design of non-backed weaves for supplementary threads was approached using the design method of a full-colour compound structure. In this case, the full-colour technical points were applied for joint weave directly, as shown in Fig. 6.12.

Fabric effect

Based on the application of basic gamut weaves and the joint non-backed weave designed above, through an appropriate combination method (i.e. with a combination proportion being 1 : 1 cross weft between colouring thread and supplementary thread) the black-and-white simulative fabric was produced. Figure 6.13 shows the real fabric created by the compound structure in which two threads were employed, i.e. a black figuring weft and a white supplementary weft. Due to the application of supplementary threads and a corresponding full-colour structure, adjacent figuring threads arranged in juxtaposition were not covered by each other. All the weave variations of the figuring weft are displayed on the face of the fabric.



6.13 Fabric effect of simulative design with compound structure.

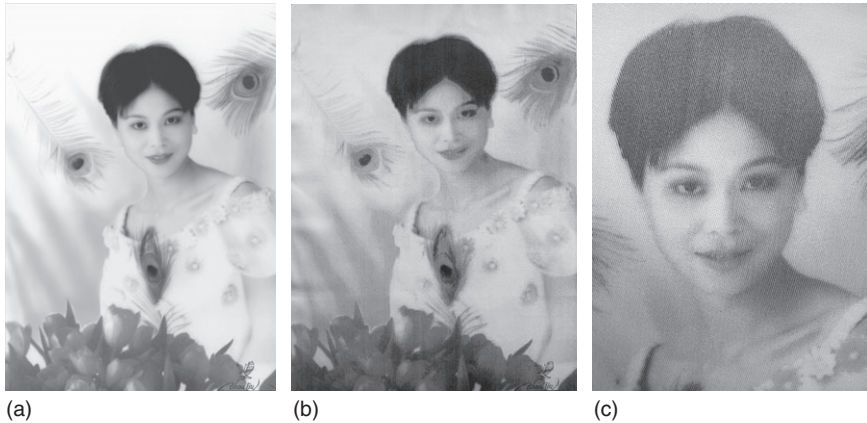


6.14 Simulative design with dragon motif and compound structure.
(a) Original image; (b) fabric; (c) detail.

Moreover, since the supplementary thread is finer than the figuring thread, it can hardly be seen from the face side of the fabric and thus does not affect the face effect of the fabric very much.

Given the structure design principle mentioned above, if the key fabric parameters remain unchanged, the designed gamut weaves and corresponding joint weave can be used to design simulative effect fabrics with any digital grey images. Figure 6.14 shows a design creation with a decorative dragon motif. The image/fabric size is 6000 pixels/needles \times 4704 pixels/fillings. Figure 6.15 shows another design creation with a portrait motif of an image/fabric size of 4000 pixels/needles \times 2496 pixels/fillings.

From the design creations of black-and-white simulative fabric designed with a compound structure, it can be concluded that following the layered-combination design mode and design method of a full-colour compound structure, the black-and-white simulative effect of jacquard fabric can be realised, and the fabric effect produced will be close to a true-to-original effect. On the other hand, given the application of two wefts, of which one serves as a supplementary thread, and giving consideration to the covering effect between figuring and supplementary threads, the design method of a



6.15 Simulative design with portrait motif and compound structure.
(a) Original image; (b) fabric; (c) detail.

simulative fabric with a compound structure would be better applied to design creation with a higher thread density and a larger weave repeat of gamut weaves.

6.5 Design of colourful simulative effect fabrics

This section discusses the application of an innovative layered-combination design mode and full-colour compound structure to the design of colourful simulative fabrics.

6.5.1 Background

Colourful true-to-original fabric has been difficult to design manually due to the complexity of the fabric structure. Thus, the design creation of colourful simulative fabrics has lagged behind in terms of advanced woven technology. With the application of CAD systems, colourful jacquard fabrics have been able to be designed by mixing basic colours that enable the number of mixed colours on the face of the fabric to exceed hundreds. A new chapter has been opened in the design of simulative effect fabrics, reproducing colour and patterns from 2-D artwork. However, the simulative effects reproduced on jacquard fabrics by CAD systems have remained unsatisfactory due to different theories of colour mixing and colour expression between the 3-D woven fabric structure and 2-D artwork. Additionally, the traditional plane design mode was employed as the basic design principle for jacquard fabric CAD systems. Jacquard fabric was designed by designating basic colours to a scanned digital image, and the fabric

structure was then designed following a one-to-one corresponding principle (Zhou *et al.*, 2006b). Shortcomings were evident. Since secondary colours cannot mix to form a primary colour, the designated colours lost some colour information. Further, designing the structure in designated colours with shaded weaves poses no problem in single-layer structure fabric: however, when designing compound structures by the combination of several single-layer structures, the application of shaded weaves leads to some of the threads being covered by one another. In order to reduce/remove the colour aberrations, tailor-made patterns and weave structures are necessary. However, the layout of the image and the number of colours is restricted. Today, another design method is available for designing colourful simulative fabric, viz. using a computer colour matching system (a colour table way) (Li, 2004a; Osaki, 2001; 2003). A colourful simulative fabric can be approached more efficiently based on a fixed colour table. The design process starts with the design of coloured fabric samples under a designated fabric structure; then, colour parameter data are tested and collected for each sample by using the computer system to establish a corresponding colour table; finally, simulative fabric is designed by matching colours between the colour table and the colour image with the aid of the computer system. By doing so, it is possible to accurately translate the colours of a given image into fabric structures. Colour matching in a computer system is especially suitable for the computer programmed processing of true-to-original simulative effect fabrics. However, due to the restrictions of the colour range of a colour table, such a method is used only to design fabrics with the same fabric specification. If the technical parameters in the fabric specification vary, new colour samples and corresponding colour tables need to be established, which is time-consuming indeed.

From the analysis described above, it is evident that the key problem of colourful simulative fabric design lies in structure design. Without an appropriate structure-design method, a compound structure of jacquard fabric that eliminates slippage and mutual covering between colour threads cannot be produced. The layered-combination design mode proposed for digital jacquard fabric design in this book proves to be an innovative structure design method for colourful simulative fabric. The application of the layered-combination design method has enabled jacquard fabric to express mixed colours at a mega level on the fabric surface. Moreover, a compound full-colour structure, with the colour threads arranged in juxtaposition, displays fully without slipping and covering (Zhou, 2007a). Such a design method efficiently governs the colour mixing of threads based on the variation of compound structures. Therefore, it is apparent that innovative designs of colourful simulative fabric can be realised as long as the problem of colour deviation caused by the difference in colour mixing principles

between fabric structure and objective image can be solved. This will enable jacquard fabrics to imitate a digital image exactly.

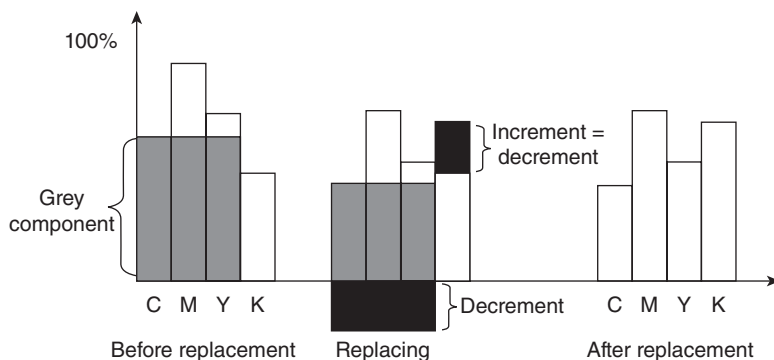
6.5.2 Design principles and methods

Colour threads of compound full-colour structures arranged in juxtaposition with even number groups are capable of expressing a smooth, colourful shading effect. Accordingly, a kind of colour mixing theory suitable for the colour mixture of non-transparent threads of jacquard fabric has been established. With the change of floating length of threads, the juxtaposed colour threads can show a multicoloured colour-mixing effect. As long as appropriate colour separation and colour combination methods for colourful digital images under the layered-combination design mode can be invented and optimised, the colourful simulative jacquard fabrics created will be able to accurately imitate the colour and image effects of digital images.

Principles and methods of colour design

The colour principle of jacquard fabric based on the colour mixing of non-transparent colour threads is different from the subtractive colour principle of transparent printing or the additive colour principle of computer screen display. Yet, what they have in common is producing mixed colours through limited primary colours.

Since mixing primary colours can produce secondary colours and tertiary colours, but not *vice versa*, primary colours are the best selection for colour separation of digital images. Indeed, one of the main reasons for colour deviation caused in colourful simulative design is the use of non-primary colours. Colour mixing of colour threads belongs to non-transparent colour mixtures, whose colour mixing principle is different from that of the RGB additive colour mode of chromatic light (consisting of the primary colours: red, green, and blue). Hence, the CMYK (cyan, magenta, yellow, kohl(black)) subtractive colour mode of digital printing is the optimal selection for colour separation of a digital image. In addition to identifying primary colours for colour separation, another important result in the study is to have identified an optimal method to help eliminate colour deviations in fabric design. In theory: $M + Y = \text{Red}$, $C + Y = \text{Green}$, $C + M = \text{Blue}$, $C + M + Y = K$. Yet, in practice, colour threads are arranged side by side instead of overlapping transparently. The frequent colour deviation of colour mixture in simulative effect fabric design is a result of colour influence by surrounding colour threads, and the difference in saturation of the primary colours of the material(s) used, notably between dyed colours and mixed black. For this reason, resolving the problem of colour deviation during the

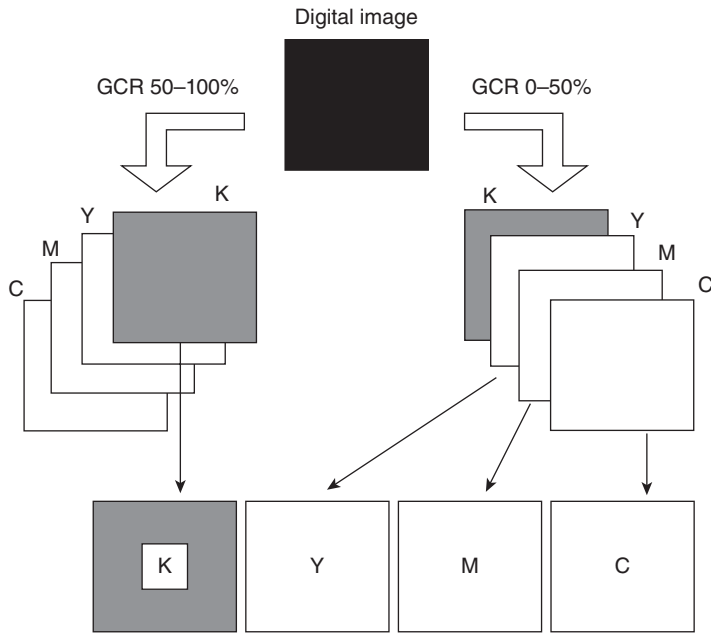


6.16 Theory of grey component replacement.

colour and structure design processes is the key to colourful simulative fabric design (Zhou *et al.*, 2006b; Zhou and Ng, 2007c).

The reason for colour deviation in black is that black thread cannot cover other colourful threads when mixing colour with juxtaposed threads because it results in a reduction of the black ratio. Through design experiment, it has been found that such a problem can be solved by the grey component replacement (GCR) technique. GCR is a technique in digital print processing to replace grey tones formerly made by mixing magenta, cyan and yellow with black ink (Hu, 1993; He, 2004). By using black to replace the grey components formed by colours, the consumption of colour printing ink is reduced. Since GCR does not affect the colour components of the original image, the colour effect of the printed image remains unchanged when applying the GCR technique. The theory of GCR for mixed colour is shown in Fig. 6.16.

When the GCR technique is applied, the grey component formed by colours can be set apart from the colourful component. It is possible to increase the grey component of mixed colour without having an effect on the colour component of the original image. To this end, the innovative design method for colourful simulative fabric design is to separate the CMYK colours of digital images with different values of GCR twice. The colour layers and the black layer are thus formed. After combining the CMYK layers that are formed by double separation, the compound fabric structure will feature a unique colour character of grey component compensation. By adjusting the ratio of GCR, the degree of grey compensation can be changed accordingly. Subsequently, the optimal grey effect of each layer is obtained (see Fig. 6.17). Additionally, as far as the problem of insufficient saturation of primary colours found in mixed colours is concerned, the proper solution is to set three adjustable colour palettes of primary colours for selection of colour threads. The first colour palette



6.17 Method of grey component replacement via double CMYK separation.

ranges from magenta to red; the second from yellow to green; and the third from cyan to blue. Moreover, in each colour palette, the grade of hue between two primary colours can be established based on practical design application. In some cases, the three adjustable colour palettes could contain all the hues necessary for design creation of a colourful digital fabric. However, in most design cases with a normal image, insufficient saturation found in mixed colours has little effect on the fabric in practice. Thus, the application of CMY primary colours is enough to meet the requirements of most simulative effect design of colourful jacquard fabric. Only when a special colour preference for a red, green or blue primary colour (i.e. where red, green or blue colour effects dominate the digital image) would other colours in the three colour palettes be selected for colour consideration and adjustment.

Principles and methods of structure design

The colour effects of digital jacquard fabric are mixed by juxtaposing colour threads in a woven structure, and it is thus imperative to devise a reliable method of structure design that enables juxtaposed colour threads not to be covered by each other as a result of slippage of the threads. The

compound full-colour structure design method has proved to be a viable means of meeting such technical requirements. Experiments have confirmed that interlacing one group of white thread and four threads of CMYK primary colours in juxtaposition can produce a compound structure that is able to achieve a colourful shading effect with full-colour presentation. It is similar to drawing a colourful image on white paper with only four colour threads, i.e. like CMYK in a woven structure. In addition, since the full-colour compound structure is stable and regular, the mixed colour on the face of the fabric in each individual colour layer can be adjusted freely, in pursuit of various design creations for any digital image.

In addition to the full-colour compound structure, another outcome emerging from the study is the realisation of an accurate transformation between colour and fabric structure. Below are the detailed design methods of this transformation:

- (i) Following the move from a 'colourless' to 'colourful' mode of layer-combination design, the four CMYK images generated through colour separation are transformed into grey images in order to realise precise replacement between colour and fabric structure.
- (ii) The first step taken in the structural design is to conceive and design the primary weave and corresponding full-colour technical points based on the fabric specification. Then, the design of shaded weaves and the establishment of a full-colour basic weave-database and joint weave-database follow. If the weave number in each of the two weave-databases is N , then N also represents the maximum number of grades of grey for each digital grey image, with brightness values ranging from 255 to 0.
- (iii) When N as the maximum value to merge with the grey-scales of four grey images, the grey grades of each grey image could be different, yet, the maximum number of grey grades is N lest there will not be enough gamut weaves for replacement.
- (iv) If the brightness values are taken as the standard of replacement between greys and weaves, with a fixed starting point, the grey-scales in the C and Y grey images could be replaced by basic weaves, while the greys in the M and K grey images could be replaced by joint weaves. As a result, four colourless images with single-layer structures would be formed, which would look like four irregular weaves with large weave repeats.
- (v) When the four single-layer structures designed from the CMYK colourless images in the proportions of 1 : 1 : 1 : 1 cross weft are combined, a compound structure that exhibits a full-colour effect would be formed, of which the precise true-to-original information of image and colour remain unchanged.

Together with the weft selection, the compound structure produced can be used to directly produce a four-weft true-colour simulative fabric. Normally, the colours of the wefts are CMYK while the colour of the warp is white. If the colour effect needs to be adjusted, cyan or blue should be selected for the first weft thread; magenta or red for the second weft thread; yellow or green for the third weft thread; and black for the fourth. The warp thread colour remains white. Additionally, if the compound structure simulative effect fabric is rotated by 90 degrees, together with weft selection information, a simulative fabric with four-group warps will be produced. However, the colour arrangement of threads should be also transformed accordingly, in which the warp thread colours are juxtaposed CMYK and the weft colour is white.

From the design principles and methods discussed above, it can be concluded that when designing colourful simulative fabric by separating CMYK colours twice, colour threads may employ CMY primary colours directly. If the applied digital images have a special colour preference to red, green or blue colours, three adjustable colour palettes (viz. magenta–red, yellow–green, and cyan–blue) are required to be set up for colour consideration and adjustment. In fact, the method of using adjustable colour palettes benefits not only the design creation of simulative fabric, but also the design creation of innovative effect fabrics based on the simulative effects of digital jacquard fabric.

6.6 Design illustrations for colourful simulative effect fabrics

In order to clearly explain the design principles and methods introduced above, particular designs of colourful simulative fabric in both basic and variant design, with detailed technical fabric parameters and design processes, have been used as examples. The merits of design creation in layered-combination design mode are highlighted.

6.6.1 Basic design of colourful simulative effect fabrics

Technical specification

The key technical parameters of a fabric are outlined in the technical specification shown in Table 6.3. For this design, the colourful simulative fabric was made with polyester materials and constructed with one white warp thread and four weft threads of CMYK primary colours; the weft density was larger than the warp density. This means that four weft threads dominate the figuring and colouring effects on the face of the fabric. Since the warp thread density was lower, the weave repeat of gamut weaves applied

Table 6.3 Technical specification of colourful simulative fabric

Parameters	
Materials	
Warp	1/166.7 dtex polyester (white)
Weft	1/166.7 dtex polyester (C/M/Y/K)
Density	
Warp	45 threads/cm
Weft	90 threads/cm
Composition	Polyester 100%
Weave structure	16-thread gamut weaves, 53 grey grades
Design repeat	1248 needles \times 2496 fillings
Pattern repeat	22.01 cm (width) \times 44.02 cm (length)
Weight	247.5 g/m ²

in the fabric's structural design was 16, and 53 gamut weaves were designed in each weave-database, in terms of the design method of full-colour compound structure. In addition, a portrait motif was selected for the design creation of a colourful simulative fabric.

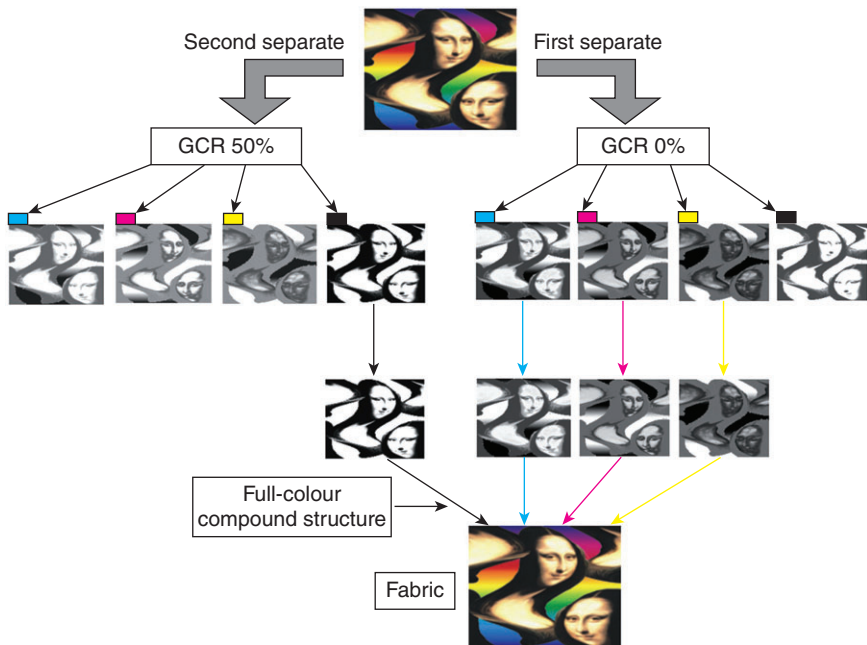
Design processes

The design of a colourful simulative fabric should be approached following the layered-combination design mode, and with a full-colour compound structure design method. Based on the fabric's technical specification, the design processes consist mainly of pattern design and structure design. In this case, in order to fully illustrate the value of the layered-combination design mode, a portrait motif together with a colourful shading effect background was selected. The digital image is shown in Fig. 6.18, whilst the colour processing is shown in Fig. 6.19, in which the CMYK digital colour mode was applied for colour separation and reproduction. The colour design method involved separating the digital image into the four CMYK layers twice, each time with different percentages of GCR. In the first colour separation, the GCR was 0% and the three layers of CMY were selected; in the second colour separation, the GCR was changed to 50%, and the black layer was selected. With the application of the GCR technique in colour separation, the saturation of achromatic colours was apparently enhanced while the colour components of CMY colours remained unchanged. Therefore, the achromatic colour effect reproduced on the face of the fabric could be improved as well.

The colour theory and method of colour separation mentioned above are suitable for producing true-colour simulative digital jacquard fabrics. However, without using certain methods of structural design, colour

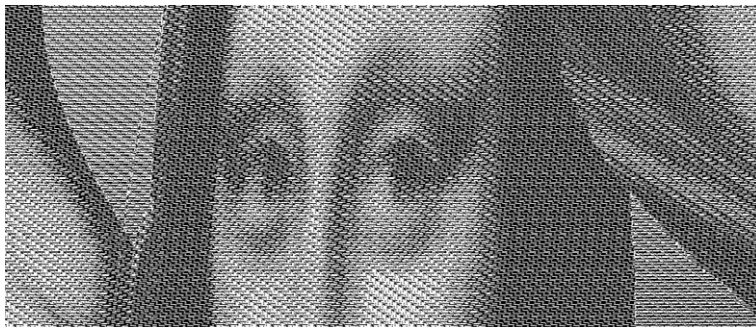


6.18 Digital image for basic design of true-colour simulation.



6.19 Colour processing for separation and reproduction.

aberrations are always likely to be present in any simulative effect design of jacquard fabric: therefore, the appropriate structure design method lays the most important foundation for the design creation of true-colour simulative fabrics. Thanks to the innovative design method of the full-colour compound structure, the design of a non-backed compound fabric structure



6.20 Detailed partial effect of compound fabric structure.

(constructed with four juxtaposed threads arranged in the proportions of 1 : 1 : 1 : 1) has been made possible. If a group of threads with four primary colours were interlaced with one white thread, such compound full-colour structure would be capable of expressing the true-colour simulative effects of a digital colour image. According to the fabric parameters specified in Table 5.3, in the case of this design, a 16-thread satin has been applied to design gamut weaves and to a full-colour compound structure; basic gamut weaves are shown in panel (a) C16-4w-j53 of Appendix 1, section A1.2 and corresponding joint gamut weaves in panel (b) C16-4w-j-z53 in the same section. The basic gamut weaves were used to design single-layer structures of the C and Y layers, and joint gamut weaves were applied to the M and K layers; after the combination of the four CMYK single-layer structures, a compound fabric structure took shape. Figure 6.20 shows a detailed partial effect of the compound structure.

Fabric effect

The colourful simulative fabric was produced by using one white warp thread and four weft threads of CMYK primary colours. The fabric effect is shown in Fig. 6.21 (and in Appendix 3, section A3.2). In comparison with the original digital image, the simulated effects of the final fabrics are satisfactory, though colour saturation is still defective, especially for the black. From the design illustration introduced, the conclusion can safely be drawn that the full-colour compound structure, designed according to the digital colourful mode, benefited the design of a true-colour simulative fabric very well. Moreover, it proved that if the major fabric technical parameters remain unchanged, the basic and joint gamut weaves designed could be used to create colourful simulative fabric from any digital image. This is of great benefit in reviving the potential of the textile designer and in broadening the design scope of fabric creation.



6.21 Fabric effect of colourful simulative design.

It should also be noted that due to the difference of colour mixtures between jacquard fabric with full-colour compound structure and art objects such as paintings, prints and photographs, the mixed colour effect of jacquard fabric cannot fully reach the same colour saturation as that of an original digital image. Therefore, the nature of the reproduced fabric is a kind of relative imitative effect, embodied in the unique features that only belong to woven structures. In other words, the unique nature of fabric cannot be ignored in the design creation of simulative jacquard fabric; it may highlight the fascination of digital jacquard textile design under the layered-combination design mode.

6.6.2 Design variation in colourful simulative fabrics

In addition to the basic design illustrated in Fig. 6.21, interesting design variations based on the simulated effect produced by the basic design are introduced, which highlight the superiority of digital jacquard textile design under the layered-combination mode.

Technical specification

Design variations of colourful simulative fabric were approached with a higher fabric density, and silk threads in both warp and weft directions. The key technical parameters of the fabric are listed in Table 6.4. The digital image selected for design creation is the same as that of the basic design.

Table 6.4 Technical specification of design variation of colourful simulative fabric

Parameters	
Materials	
Warp	22.2/24.4 dtex \times 2 silk
Weft	22.2/24.4 dtex \times 5 silk (C/M/Y/K)
Density	
Warp	115 threads/cm
Weft	90 threads/cm
Composition	Pure silk 100%
Weave structure	24-thread gamut weaves, 85 grey grades
Design repeat	12 000 needles \times 9600 fillings
Pattern repeat	104.3 cm (width) \times 106.6 cm (length)
Weight	175 g/m ²

Design processes

Given the basic design of colourful simulative fabric, the variant design can be made through a change in the layered-combination fabric structure. This embodies the merits of the layered-combination design mode and the capability for the designer to produce digital jacquard fabrics with picturesque effects that would otherwise be impossible to achieve using the traditional plane design mode. Since the layer-combination fabric structure is a kind of compound structure featuring a full-colour effect, changing the disposition of the fabric structure in each layer will generate a series of creative effects that exhibit various unique woven effects. Figure 6.22 shows the real fabric effect based on the colourful simulative effect design. It was approached through the employment of weft threads of CMYK colours. The design method was to reduce the colour layer gradually from four layers of CMYK (the true colour effect) to none (a no colour layer). As a result, a total of 16 colour effects were created within one motif. Similarly, Fig. 6.23 shows another creative fabric effect based on the same basic simulation design. In this example, the design method changed to one with the four colour layers of CMYK being gradually reversed from one layer to four layers (a reversed effect). By doing so, 16 colour effects within one layout also were created.

Additionally, based on the design results of the two creations shown in Fig. 6.22 and Fig. 6.23, it is possible to create a design by means of integrating the 32 fabric effects. Relatively sophisticated integrative fabric effects can be further realised by manipulating these 32 effects. An interesting fabric effect created by such a method is shown in Fig. 6.24 and in

MYK	MY	Y	YK
MK	M	None	K
CMK	CM	C	CK
CMYK	CMY	CY	CYK

(a)

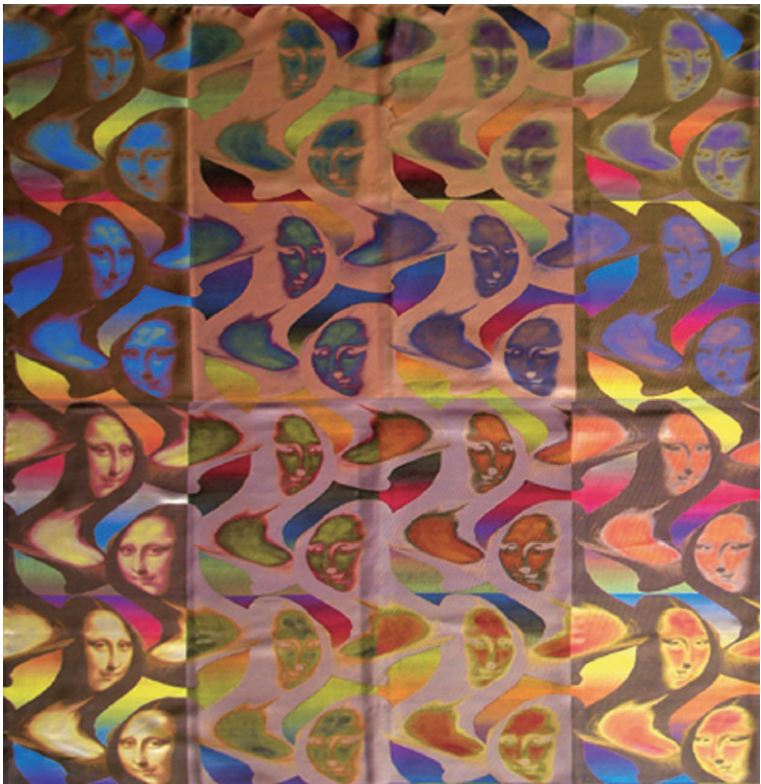


(b)

6.22 Variant design by reducing colour layers. (a) Layers used; (b) final effects.

CMYK	CMYK	CMYK	CMYK
CMYK	CMYK	Reversed	CMYK
CMYK	CMYK	CMYK	CMYK
CMYK	CMYK	CMYK	CMYK

(a)



(b)

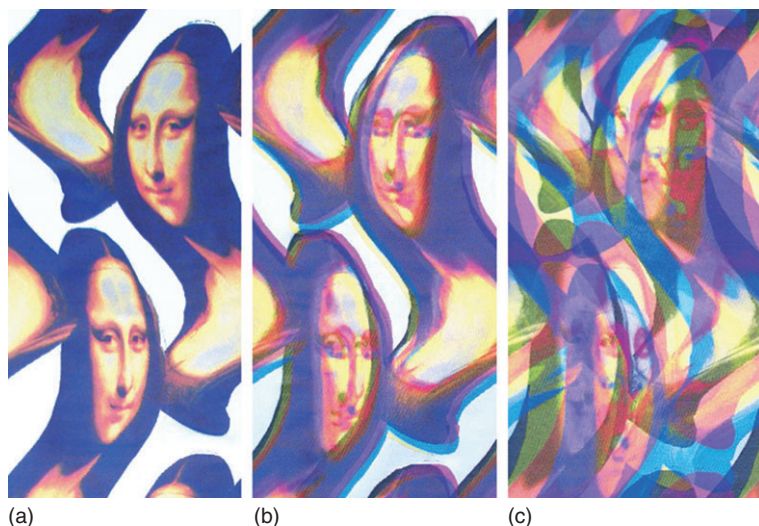
6.23 Variant design by reversing colour layers. (a) Layers used; (b) final effects.



6.24 Variant design by integrative method of changing layers.

Appendix 3, section A3.3. These effects have expanded the creative scope of novel art styles for jacquard fabrics, through woven structure.

Since the full-colour effect of the compound structure is determined by the design methods of gamut weaves and the combination methods of single-layer fabric structure, the change of image applied has no effect on the structure of a full-colour non-backed compound fabric. In addition to the variation in design realised by changing the deployment of a layered compound structure in a fixed position, the fabric effect produced by the basic design method of true-colour simulative effect can also be altered by shifting individual layers of the compound structure. By doing so, the fabric created can exhibit various combined fabric effects. Figure 6.25 (and also Appendix 3, section A3.4) shows the fabric effect of the variant design achieved by shifting the layers of the compound structure. In Fig. 6.25, panel (a) shows the original fabric effect designed by the basic method of true-colour simulative fabric; (b) shows the fabric effect designed by slightly shifting individual layers of the compound structure; and (c) shows the results achieved by considerably shifting individual layers of the compound structure.



6.25 Variant design by shifting the layers of compound structure.

From the design variations of colourful simulative fabric presented above, it is not difficult to realise the potential applications of the layered-combination design mode proposed in this book. For example, it can be applied not only to colourful simulative design targeting true-to-original simulation, but also to the realisation of the many variant designs of innovative jacquard fabric. By using such a structure, the fabric effects of jacquard fabric can now achieve a much wider range of simulation and innovation than jacquard fabric could traditionally conceive and realise. Last but not least, the fabric effects obtained through variant designs of simulative fabric cannot be copied by other means of artwork because of the inimitable digital fabric structure and its random colour expression.

6.7 Simulation design from colourful to black-and-white effects

In addition to the two design methods of black-and-white simulative fabric already introduced, it is possible to design black-and-white simulative fabric based on the designed compound fabric structure of colourful simulative fabric itself. For the design of the digital image, decolourising a colourful digital image can produce a grey digital image. Similarly, if the weft colours of a colourful simulative fabric were transferred into grey-scales with the same levels of brightness and under the same fabric structure, black-and-white simulative fabric could be produced from a colourful simulative fabric structure without any additional structural design procedure. Following this

Table 6.5 Technical specification of fabric from colourful to black-and-white

Parameters	
Materials	
Warp	22.2/24.4 dtex × 2 silk
Weft	22.2/24.4 × 2 dtex silk (CMYK-greys)
Density	
Warp	115 threads/cm
Weft	160 threads/cm
Composition	Pure silk 100%
Weave structure	24-thread gamut weaves, 85 grey grades
Design repeat	4000 needles × 4416 fillings
Pattern repeat	34.8 cm (width) × 27.6 cm (length)
Weight	141.5 g/m ²

idea, an appropriate design illustration was approached to produce a black-and-white simulative fabric directly from a colourful simulative fabric structure. Table 6.5 shows the technical specification of fabrics with both true-colour effect and black-and-white effect.

The black-and-white fabric was made with pure silk threads and has a higher thread density in both warp and weft directions than the colour design. The design processes are the same as that for the colourful simulative fabric, accomplished by colour separation and combination of CMYK primary colours; however, in the course of fabric production, four grey colours were employed to replace the CMYK primary colours, respectively, with the same levels of brightness, and were applied to the fabric production. In other words, four grey colours instead of the CMYK primary colours produced the fabric, notwithstanding the fact that the fabric structure was designed in CMYK true-colour mode. Figure 6.26 (and also Appendix 3, section A3.5) shows the fabric effect of both true-colour and black-and-white simulative fabrics.

6.8 Conclusion

In this chapter, based on the application of the layered-combination design mode, the innovative design methods of true-to-original effect jacquard fabric, both black-and-white and colourful simulative effects, have been introduced with illustrations. Several valuable results have been obtained from the practical design research of simulative effect design of jacquard fabric, inspiring further attempts at design creation of digital jacquard textile under the layered-combination design mode. For black-and-white simulative effects, three available design methods were introduced: design with a single-layer fabric structure, design with compound fabric structure,



(a)



(b)

6.26 Simulative fabric effects from true-colour to black-and-white.
(a) True-colour effect; (b) black-and-white effect.

and design by decolourising the colourful simulative design. Based on the results of research on the design of black-and-white simulative fabric, it is concluded that for lower density fabric design, the design method of single-layer fabric structure is the optimal selection, whereas for the design of black-and-white simulative fabric with higher thread density, the design method with compound fabric structures (of both two threads and four threads) has proven to be the best. As for colourful simulative effect, in order to resolve the problem of colour deviation generated during true-to-original colourful simulation, our research proposes a series of resolutions including grey-scale compensation via double colour separation, the precise transformation between colours and structure, and setting adjustable colour palettes for basic colour selection.

In addition, since both black-and-white and colourful simulative designs are required to be processed on a structure design method, it has been proved that the mixed colour effects constructed with warp and weft threads are firm and stable on the face of the fabric, thus allowing such fabric structure for industrial manufacturing. So long as the fabric specification is planned thoroughly before design and production, and corresponding weave-databases of gamut weaves are built, there is literally no restriction in the selection of digital images. Therefore, the results achieved from the study hold promising prospects for wide creative and commercial applications. In short, from the research into the design of simulative effects of digital jacquard fabrics presented in this chapter, the proposed layered-combination design mode has been shown to offer tremendous application value and technological advancement for simulative jacquard fabrics, of both black-and-white and colourful effects. It has proved to be a powerful creative and productive tool of high commercial value, and has already inspired future research.

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Digital design of shot-effect and double-face effect jacquard textiles

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Abstract: This chapter introduces design creations in innovative digital jacquard fabric under the layered-combination design mode, and proper design illustrations in both figured shot-effect digital jacquard fabric and figured double-face digital jacquard fabric.

Key words: digital, jacquard, woven, fabric, layered-combination, figured, shot effect, double face.

7.1 Introduction

Traditional jacquard fabric design was a mechanical process that imitated the colour and pattern effects of freehand paintings by means of a complex design process and fabric construction. The layered-combination design mode has made the digital design and production of jacquard fabric possible. As a result, the complex fabric construction has been systematically regulated and the design process made much more efficient. This has contributed significantly to the innovative design and production of digital jacquard fabric. Shot-effect and double-faced fabric are unique varieties of traditional jacquard. Their artistic effects cannot be imitated by any other means. This chapter considers the application of the layered-combination design mode and full-colour compound structure as innovative design methods. Detailed design illustrations and fabric technical specifications are provided. In the course of this practice-led design research, a digitally based design procedure was introduced from basic to variant design. The creative values and commercial viability of the proposed digital design methods were confirmed by comparison with traditional methods.

7.2 Design of figured shot-effect fabrics

Shot-effect fabric is woven with dyed yarns, giving a warp of one colour and a weft of a contrasting colour. Shot effect is usually associated with fabrics of plain or 2/2 twill weave, e.g. chameleon taffeta (Denton and Daniels, 2002). Due to its simple fabric construction, it is impossible to produce a figured shot-effect fabric by using the traditional plane design mode. A research study was conducted on the creation of digital jacquard fabric with

novel figured shot effect through the use of the layered-combination design method and full-colour compound structure. The figured shot effect was realised by means of two digital images featuring the relationship of a reversed negative.

7.2.1 Background

The literature defines shot effect as a special effect among woven fabrics. The warp and weft of these fabrics are interlaced with contrasting colour threads. In three-dimensional woven structures, the colour ratio of the warp and weft may change under different angles of view, so altering the colour effect of the fabric. Traditional shot-effect fabric is constructed with a single-layer structure in plain weaves, using lustre threads with a contrasting colour effect within a warp and weft groups, e.g. a plain weave or variations of plain weave. The colour threads of the warp and weft are arranged in different directions and do not cover each other. When they are viewed from different angles, the colour ratio of the warp and weft threads therefore change accordingly. When contrasting colours are employed, the changing effect is exhibited on the face of the fabric. This is described as the 'shot effect'. In simple weaves and single-layer fabric structures, only a plane shot effect without any pattern effect is exhibited. Experiments show that a 'figured' shot effect can be achieved with complex jacquard weaving. The objective of jacquard fabric design using the traditional plane design mode was to imitate the colour effect of freehand patterns by an appropriate woven structure. Even when complex backed weaves and double-layer weaves are used for designing fabric structures, and where complex weaves are constructed by the combination of primary weaves, the compound fabric structures thus created show a limited mixed colour effect in which the interlacing points cover each other. It is therefore not yet possible to design figured shot-effect fabrics with complex patterns.

7.2.2 Basic design concept

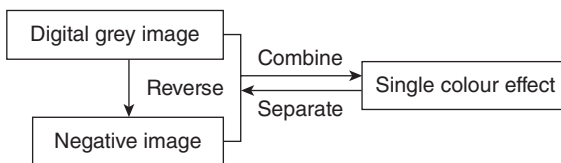
The layered-combination digital design mode and the invention of a design method for full-colour compound structure may overcome the technical deficiency described above. The basic design concept follows the design method of full-colour compound structure: two single-layer fabric structures are designed separately, based on a digital grey image and its negative grey image. By combining the two structures, a full-colour effect is created in which the colour ratio of the threads arranged in juxtaposition can be freely changed. By using threads with contrasting colours, a multicoloured shot-effect jacquard fabric can be produced. This fabric pairs threads with contrasting colours arranged in the same direction, unlike traditional

shot-effect fabric in which contrasting colours are arranged in different directions. A full-colour compound structure also enables the colour threads interlaced in the fabric construction to exhibit smooth colour shading. Fabric with this structure is capable of expressing a figured shot effect with both contrasting figures and contrasting colours when fine lustre colour threads are used.

7.2.3 Design principles and methods

Principles and methods of colour design

The colour mixing of jacquard woven fabric is non-transparent. It differs from that of transparent printing colours or computer colours. The mixed colours on the face of a fabric will change when viewed from different angles as the woven structure is formed by solid interlacing, i.e. an up/down construction of warp and weft threads. The design of traditional shot-effect fabric usually employs a plain weave or variant to produce the changing colour effect in which the warp and weft threads have contrasting colours with a fixed colour ratio. Although two contrasting colours are arranged in different directions, the amount of colour (the sum of floating length with contrasting colours) on the fabric surface is a constant. When viewed from different angles, the colour ratio of the contrasting colours varies, while the amount of colour remains almost unchanged due to the solid interlacing structure. When certain contrasting colours of warp and weft lustre threads are used, a shot effect is produced. By use of the the layered-combination design mode together with the colourless design mode, a digital jacquard fabric with a smooth black-and-white shading effect may be obtained. A combination of several single-layer digital jacquard structures will produce a high level of mixed colours on the face of a fabric. In pairing digital images, the superimposition of an original grey digital image and its negative image will create a combined colour image with a constant colour value. The combination of several images consisting of the original grey images paired with their negatives gives a mixed colour effect which is equal to the single colour effect. In other words, the mixed colour effect of an original grey image and its reverse is distinct from that of a single colour (Fig. 7.1). This



7.1 Colour design principles and methods of figured shot effect.

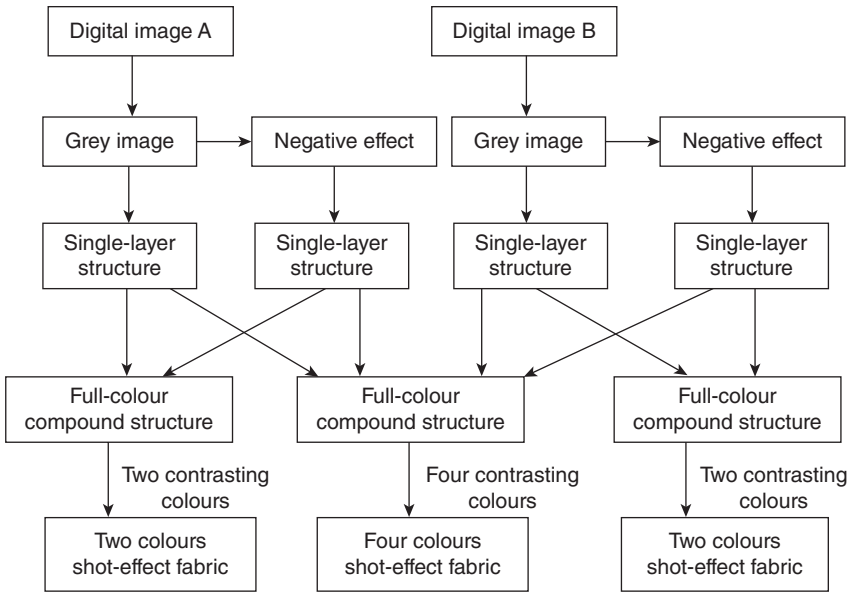
is a structural combination in which the weaving pattern of each image remains self-juxtaposing without any overlapping.

Based on the colour design principles and methods described above, an attempt was made to resolve the key technical problem of the colouring principle to produce shot and figured effects. It was found that if the appropriate structural design methods were used in arranging the contrasting colour threads in juxtaposition with equal colour values, and the threads were not covered, a shot effect would be produced. The figured effect could be realised through a change in the colour ratio of the contrasting colours. As a result, the dual effects of colour contrast and figured contrast are simultaneously present in the compound fabric structure. Digital jacquard fabric produced by this method exhibits novel and interesting figured shot effects.

Principles and methods of structure design

Research on the colour design principles of shot-effect fabric indicates that a constant colour value of threads with contrasting colours is the foundation for producing the shot effect. The selection and application of threads with contrasting colours and lustres changes only the degree of the shot effect. Structural design is the key to innovation in shot-effect fabrics and requires the use of the jacquard design method. As jacquard fabric with a single-layer structure is figured by a single warp and a single weft, the figured shot effect is produced by using weaves with a shading effect, although only one pattern will be shown. In order to produce more figures with contrasting colour effects, a complex compound weave must be used in the structural design. Because traditional jacquard fabric was produced by the plane design mode in which complex structures such as backed and double-layer structures were designed with a mutual covering effect, the basic technical requirements for figured shot-effect could not be met. This type of design is possible only when the layered-combination design mode and a full-colour compound structure is employed. The full-colour compound structure requires the grouped threads to be arranged in the same direction and in even numbers, so the juxtaposed colour threads must be arranged in a paired proportion of 1 : 1 (Zhou and Ng, 2007b).

As shown in Fig. 7.2, the digital images A and B can be separated into two images with a reciprocal relation, i.e. the original grey image and its reversed image. There will therefore be two pairs of grey images. With a fixed replacement between grey-scales and weave structures, the two pairs of grey images form four single-layer structures. If these structures are combined, a four-layer compound structure is produced in which the effect of the mutual moving and covering of the juxtaposed threads may be avoided. The sum of the floating length of each pair of threads in the compound structure remains constant, so meeting the basic requirement of



7.2 Structure design processes of figured shot-effect digital jacquard fabric.

shot-effect fabric design. Because the colour ratio of the juxtaposed threads in a full-colour structure can be changed, a figured effect may be obtained in these compound fabric structures. As a result, figured shot-effect jacquard fabric with a two-colour effect can be designed upon either digital image A or B, the threads with contrasting colours being arranged in alternate juxtaposition. When shot-effects of image A and B are merged in one full-colour compound structure, a figured shot-effect jacquard fabric with four colours is produced.

7.3 Design illustrations with objective and abstract motifs

Illustrations of the design principles and methods of figured shot-effect digital jacquard fabric are introduced. These describe clearly the design methods and highlight the advantages of the layered-combination mode of digital jacquard textile design.

7.3.1 Design illustration with objective motifs

The image motif for figured shot-effect digital jacquard fabric can be divided into two types: objective motif or abstract motif. In this design, the objective motif was used.

Table 7.1 Technical specification of figured shot-effect fabric with objective design

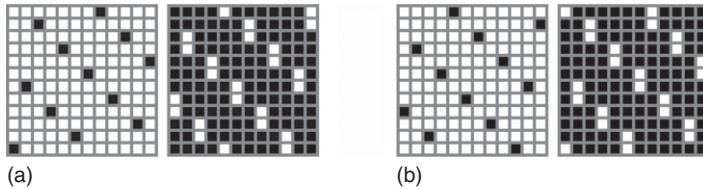
Parameters	
Materials	
Warp	1/166.7 dtex polyester (white)
Weft	1/166.7 dtex polyester (dark/dark/light/light)
Density	
Warp	45 threads/cm
Weft	90 threads/cm
Composition	Polyester 100%
Weave structure	12-thread gamut weaves, 37 grey grades
Design repeat	1248 needles \times 4096 fillings
Pattern repeat	22.01 cm (width) \times 45.5 cm (length)
Weight	247.5 g/m ²

Technical specification

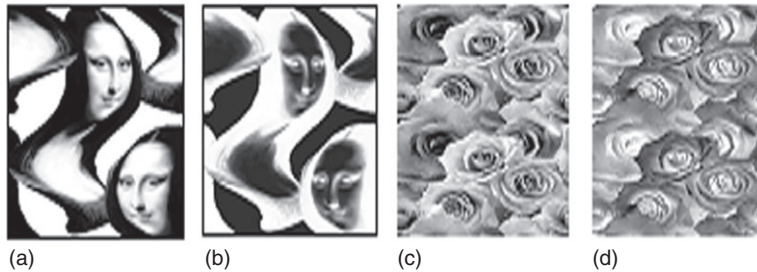
Based on the production conditions and the design motif, details of the major technical parameters of the fabric and technical specifications are shown in Table 7.1. In accordance with the major technical parameters, the final fabric was constructed by 12-thread gamut weaves with a lower thread density in the warp direction and a higher thread density weft-wise. Polyester threads were used in both the warp and weft direction.

Design processes

In this example, a 12-thread weave was used to design a full-colour structure and a weave-database. In line with the design requirements of full-colour structure, a weft-face sateen of 12 threads and 5 steps was selected for the primary weave. The starting point of Primary Weave I was (warp, weft) = (1, 1) in lower left, while the starting point of Primary Weave II was (warp, weft) = (10, 1) moved from the lower left. The full-colour technical points for Primary Weave I were set up in accordance with the character of Primary Weave II, while the full-colour technical points for Primary Weave II were set up in terms of the woven character of Primary Weave I (see Fig. 7.3). A group of shaded gamut weaves based on Primary Weave I was then designed. There were initially three enhanced weave points and, in order to make them continuous, the enhancement direction should first be to the right, then to the left, this being omitted when the full-colour technical point is encountered. In this manner, a group of basic gamut weaves with 37 shaded effects was formed and a weave-database established (see Ac12-3w-z-y41 of Appendix 1, section A1.1). Similarly, a group of shaded weaves based on Primary Weave II was designed with its enhancement direction being left



7.3 Design of primary weaves and their full-colour points. (a) Primary Weave I and full-colour points. (b) Primary Weave II and full-colour points.



7.4 (a) and (c) Digital images of design with objective design; (b) and (d) corresponding digital grey images created by reversing the grey-scale of images in panels (a) and (c) respectively.

first and then right and then omitted when the full-colour technical points were encountered. A group of joint gamut weaves with 37 shaded effects was formed, and a corresponding weave-database was established (see Ac12-3w-z-y41-9 of Appendix 1, section A1.1).

The digital grey images are shown in bitmap format in Fig. 7.4 (a) and (c). The corresponding digital grey images in Fig. 7.4 (b) and (d) were generated by reversing the grey-scales of the images in panels (a) and (c) respectively. To be in accordance with the character of the weave-database, the grey-scale of each image must be adjusted to less than 37 grades or there will be a lack of available weaves for the structural design.

Structure combination and fabric effect

The replacement relationship between the grey-scale in the digital grey images and the gamut weaves (i.e. black colour corresponding to the maximum warp-face weave and white colour corresponding to the maximum weft-face weave in the database), is fixed by replacing the corresponding grey-scales of grey images (Fig. 7.4 (a) and (c)) by the basic gamut weaves at the same starting point. When the corresponding grey-scales of



7.5 Figured shot-effect digital jacquard fabric with an objective design.

Fig. 7.4 (b) and 7.4 (d) were replaced by the joint gamut weaves, four single-layer fabric structures were formed. These structures were then combined in the proportion of 1 : 1 : 1 : 1 in the weft direction. If the single-layer structures designed from the basic or joint gamut weaves were arranged alternately, the interlacing points in the compound structure of the fabric did not cover each other, and a full-colour compound structure incorporating the two images was formed. When two groups of contrasting colours were applied, a figured shot-effect fabric with four colours and two individual images was produced (see Fig. 7.5 and Appendix 3, section A3.6).

As the compound full-colour structure features balanced interlacing, compound structure design may be directly applied to the production of multi-weft figured shot-effect fabric. It can also be rotated through 90 degrees to produce multi-warp figured shot-effect fabric. The structural design of figured shot-effect jacquard fabric and the selection of colour threads are independent of the design of the digital image. Digital images of any design may therefore be employed for the creation of digital jacquard fabric with a figured shot-effect.

7.3.2 Design illustration with abstract motifs

This design process is excellent for use with abstract images, the shot effect being superior to that created by using an objective image due to the random disposition and combination of the contrasting colour threads.

Table 7.2 Technical specification of figured shot-effect fabric with abstract design

Parameters	
Materials	
Warp	22.2/24.4dtex \times 2 silk (white)
Weft	22.2/24.4 dtex \times 5 silk (red/yellow/green/blue)
Density	
Warp	115 threads/cm
Weft	90 threads/cm
Composition	
Pure silk 100%	
Weave structure	
24-thread gamut weaves, 85 grey grades	
Design repeat	
6000 needles \times 4800 fillings	
Pattern repeat	
52.2 cm (width) \times 53.3 cm (length)	
Weight	
175 g/m ²	

Technical specification

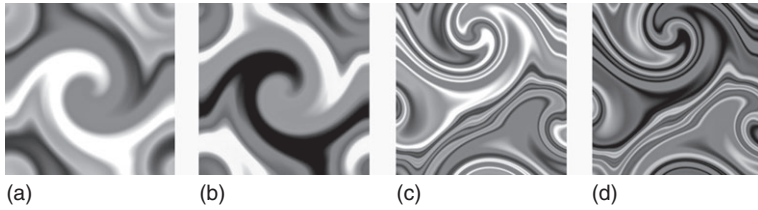
The major technical parameters of the fabric are listed in Table 7.2. The finished fabric was constructed with pure silk threads and featured a higher thread density than that of the polyester fabric previously introduced. To accord with the technical parameters of the fabric, 24-thread gamut weaves were employed.

Design processes

A 24-thread weft-face sateen with seven steps was used to design a full-colour structure and weave-database. The starting point of the weave was determined as the lower left (warp, weft) = (1, 1) and (warp, weft) = (20, 1) respectively to form two primary weaves. In accordance with the character of the two primary weaves, full-colour technical points were set up for the design of the gamut weaves. The basic gamut and joint gamut weaves were designed with the same 85 grades and are shown in panels (a) (C24-7w-j89-y-z) and (b) (C24-7w-j-z89-z-y) of Appendix 1, section A1.3. A full-colour compound fabric structure can be designed in a similar process to that using an objective image. In accordance with the requirements of designing four-colour shot-effect fabric, digital grey images are shown in Fig. 7.6 (a) and (c) and their reversed negative grey images are shown in Fig. 7.6 (b) and (d).

Structure combination and fabric effect

The replacement relationship between the 85 grey-scales in the digital grey images and the 85 gamut weaves (i.e. the black colour corresponding to



7.6 (a) and (c) Digital images of design with abstract design; (b) and (d) reversed negative grey images of panels (a) and (c) respectively.



7.7 Effect of figured shot-effect digital jacquard fabric with an abstract design.

the maximum warp-face weave and the white colour corresponding to the maximum weft-face weave in weave-database), is fixed by replacing the grey-scales of the grey images in Fig. 7.6 (a) and (c) by the basic gamut weaves, using the same starting point. The grey-scales of Fig. 7.6 (b) and (d) were replaced by the joint gamut weaves, forming four single-layer fabric structures. These four single-layer structures were then combined in the order of 1 : 1 : 1 : 1 in the weft direction. If the single-layer structures designed from the basic gamut or joint gamut weaves were arranged alternately, the interlacing points in the compound structure did not cover each other and a full-colour compound structure incorporating the two images was formed. When two groups of contrasting colours was applied, a figured shot-effect fabric with four colours and two individual images was produced (Fig. 7.7 and Appendix 3, section A3.7). As the full-colour structure featured non-backed and full-colour effects, the colour effect on the face of the fabric was a reversal of that of the reverse side. Both sides of the

fabric display a figured shot-effect, but with the colour configuration reversed.

Figured shot-effect jacquard exhibits both contrasting colour and figure effects and is one of the significant products that can be designed by the layered-combination mode. The smooth colour shading effect produced on the face of the fabric is similar to that of printed textiles, while the novel figured shot-effect is far superior to that of flat printed to that of textiles. It optimises the artistic quality of woven fabrics, which cannot be reproduced by any other means.

7.4 Design of figured double-face effect fabrics

7.4.1 Background

Double-face effect fabric is a special variety of woven jacquard that is produced by a unique structural design method. Both the face and reverse sides of the fabric are designed with their own colours and patterns (Denton and Daniels, 2002). Traditional double-face fabric can be divided into two types in terms of the effect: plain effect fabric and figured effect fabric. There are two main design methods for plain effect double-face fabric. The first employs double-face effect weaves to form a double-face, single layer fabric. The second designs a double-face fabric with compound weaves, such as warp-backed or weft-backed weaves where the face and backing weaves may be designed to have the same effect or a contrasting effect. Because figured double-face fabric has complex colour and pattern effects on both the face and reverse sides, it has to be produced on a weaving loom with the support of a jacquard machine. The alterable double-layer structure is essential to this design. The patterns on the face and reverse sides of the fabric are interwoven by grouping the warp and weft threads respectively, i.e. grouping threads on the face side of the fabric are interwoven to form a pattern on the face side, whereas the pattern on the reverse side of the fabric is constructed by grouping threads on the reverse side. For this reason, double-face fabric produced by an alterable double-layer structure displays an individual figured effect on both the face and reverse sides. This type of fabric is known as figured double-face jacquard. As an alterable double-layer structure cannot be produced by hand in the plane design mode, it has not been possible to make jacquard fabric with a figured double-face effect. However, the layered-combination design mode has overcome the limitations of hand painting and offers a solution to the problem of the efficient design and development of figured double-face jacquard fabric. The face and backing structures are designed separately and then combined by stitch weaves in the layered-combination mode. This

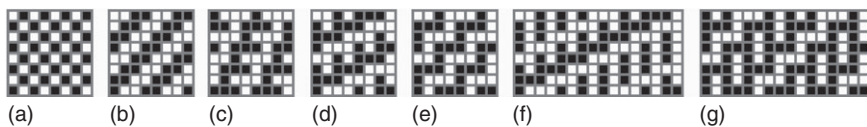
produces a compound structure that remains stable, even when the figured effects differ on each side of the fabric.

7.4.2 Design principles

A study of the design principles of both double-face and figured double-face fabric was conducted with an in-depth technical analysis to enable a thorough understanding of the key points of this innovative design.

Design principles for double-face woven fabrics

The effects on the face and reverse sides of a fabric of interwoven warp and weft threads are different. If woven fabric with a single-layer structure is taken as an example, the face and backing effects produce a reversed negative effect, i.e. the area of woven fabric with a weft-faced structure on the face side exhibits a warp-faced structure on its reverse side. However, in woven fabrics that are designed with a complex weave structure, e.g. backed or double-layer, the relationship between the face and backing effects is also complex. While certain groupings of warp and weft threads provide the colouring and figuring on the face of fabric, the remaining threads form the backing effect on the reverse side. It is therefore apparent that the key to designing woven fabric with a double-face effect lies in the fabric structural design. The simplest effect for a double-face fabric is generally that of a plain fabric designed with a plain weave, 2/2 twill, or other simple backed weave. Figure 7.8 shows the design methods for plain effect double-face fabrics displaying the same or differing effects between the face and reverse sides. Among these, panels (a) and (b) show a single-layer structure with the same effect on both sides; panels (c) and (d) present a simple backed structure having the same effect on both sides; panel (e) shows a double-layer structure with the same effect on both sides. An alterable backed structure with a double-layer structure provides the optimal selection for designing double-face fabric with different effects on both sides. For example, in Fig. 7.8, panel (f) was changed from panel (d) whereas panel (g) was changed from panel (e).

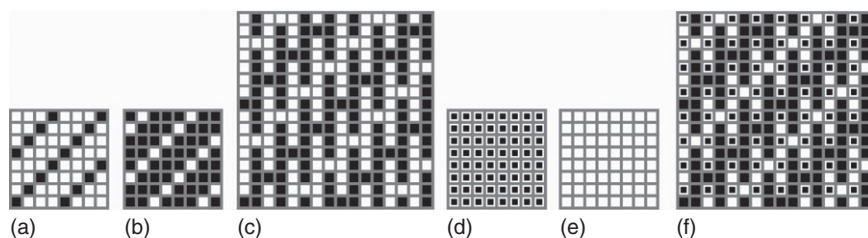


7.8 Principles of structure design for double-face fabric. (a) Single plain; (b) 2/2 twill; (c) backed 1/3 twill; (d) backed 3/1 twill; (e) double plain; (f) face 3/1 twill, back 7/1 twill; (g) face 3/1 twill, back plain.

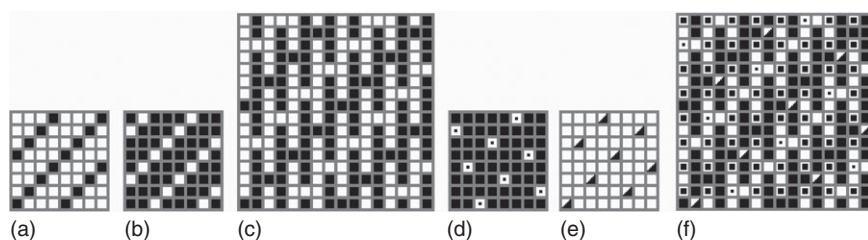
Design principles for figured double-face jacquard fabrics

A double-layer woven structure should be used for designing figured double-face fabric (Zhou, 2002b). The design processes may be divided into three parts: face weave design, backing weave design and stitch weave design. The design principles of double-layer weave are shown in Fig. 7.9. Panels (a) and (b) show the face and backing weaves respectively; panel (c) is the combined effect of (a) and (b); panels (d) and (e) are the effect of the intersection of the face warp thread with the backing weft thread and of the backing warp thread with the face weft thread respectively; panel (f) shows the compound weave structure without a stitch weave.

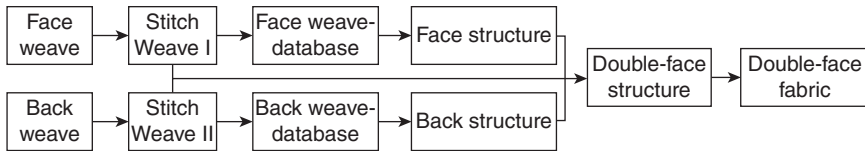
Stitch weaves were added to the weaves shown in Fig. 7.9. Double-layer weaves producing a stitching effect are shown in Figure 7.10. The results show that a better covering effect is obtained when the stitch weaves are based on the face or backing weaves as illustrated in Fig. 7.10(a) and (b) respectively. Figure 7.10(c) shows the effect when combining (a) and (b). The stitch weaves should be designed to meet the technical requirement of well balanced interlacing. Following this design rule, Fig. 7.10(d) shows the design for a stitch weave based on a backing weave by reducing the weft



7.9 Principles of structure designs in double-layer weaves. (a) Face weave; (b) backing weave; (c) combination effect; (d) interlacing effect; (e) interlacing effect; (f) compound weave structure.



7.10 Principles of structure design for double-layer weaves with stitch weaves. (a) Face weave; (b) backing weave; (c) combination effect; (d) stitch weave; (e) stitch weave; (f) compound weave structure.



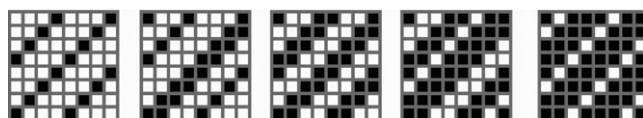
7.11 Design processes of figured double-face jacquard fabric.

interlacing points; panel (e) shows another design for a stitch weave based on a face weave by reducing the warp interlacing points; and panel (f) shows a compound double-layer structure with dual stitch weaves.

With the assistance of a CAD system, an unchanged stitch weave based on face and backing weaves may be simulated before production. If the stitching and covering effects remain constant when the face and backing weaves vary, a figured effect on both the face and reverse sides of a double-face fabric can be changed respectively. The design principle may be summarised as follows: stitch weaves are designed on the basis of the face and backing weave respectively. Taking the face and backing weaves as the primary weaves, two series of gamut weaves are then designed to apply to the face and backing structures. By combining the face and backing structures with the stitch weaves, a compound structure is created which is capable of expressing a figured double-face fabric effect in which the effects on each side are independent of each other.

7.4.3 Design methods

Using the basic design principle described above, other design methods available for the layered-combination design mode can be specified (see Fig. 7.11). This provides a valuable resource for the creation of figured double-face jacquard fabric in which the design of both the face and backing effects is independent. The method is similar to that of designing two separate single-layer structure fabrics. However, the fabric specification (key technical parameters) must differ only minimally if the structural combination is to be successful. Each of the two independent fabric structures will consist only of black and white. Black represents the points at which the warp threads should be lifted while white indicates the points where the warp threads should be kept lower. It should be noted that in designing the backing structure, the digital image is transferred from positive to negative. This causes a reversal of all the interlacing points in the fabric structure. Thus, by combining the face and backing structures, a double-face fabric with independent colours and pattern effects on each side of the fabric is obtained.



7.12 Gamut weaves design with regular variations.

Gamut weave design

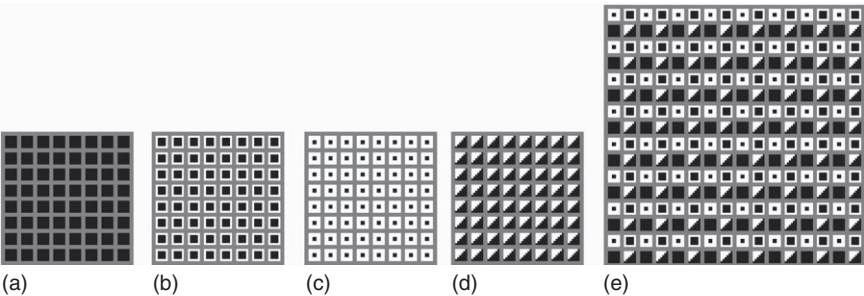
Taking stitch weaves (d) and (e) in Fig. 7.10 as the foundation, the gamut weaves used for structural design on both sides of the fabric are established. By taking the face and backing weaves as the starting and ending weaves, a series of weaves can be designed by increasing or reducing the interlacing points, and a corresponding weave-database established. The weave varies between the face and backing and Fig. 7.12 shows the design method with regular weave variations. This design method is similar to that of shaded gamut weaves. An established weave-database can be used for structural design on both the face and reverse sides. Shaded gamut weaves are designed by increasing the interlacing points one-by-one until the number of gamut weaves in the weave-database reaches its maximum. When the repetitions of a face or backing weave are increased, the number of weaves in the weave-database will also be increased. For ease of structural combination, it is therefore preferable for the face and backing weaves to share the same gamut weaves and database.

Combination methods for face and backing fabric structure

The method of combining face and backing effects in figured double-face jacquard fabric is the most important design process in innovative digital jacquard design. The basic design method is to arrange the warp and weft threads into two groups in the ratio 1 : 1. One group of warps and wefts are interwoven to form the face fabric effect. The other group is interwoven to form the backing effect in the form of backing warp and backing weft. In this way, four relationships of interwoven threads are generated: face warp and face weft, backing warp and backing weft, face warp and backing weft, and backing warp and face weft. Their corresponding structures are: face fabric structure, backing fabric structure, stitch weave of the face warp and backing weft, and stitch weave of the backing warp and face weft. The relationship is shown in Table 7.3: Stitch Weave I is formed from the face warp and backing weft, and Stitch Weave II is designed from the backing warp and face weft. Based on the relationship of the warp/weft threads and fabric structures, and fixing the starting point to combine the face and backing structure into a 1 : 1 arrangement, the weave repeat of the resultant compound structure is

Table 7.3 Relationship of warp/weft threads and fabric structures

Wefts	Face warp	Backing warp
Face weft	Face structure	Stitch Weave II
Backing weft	Stitch Weave I	Backing structure



7.13 Combination of weaves and structures. (a) Face structure; (b) backing structure; (c) Stitch Weave I; (d) Stitch Weave II; (e) compound structure.

double that of the original face or backing weave in both the warp and weft. Figure 7.13 shows that when the lower left corner is taken as the starting point for combining the face and backing structures with the stitch weave of face warp and backing weft and the stitch weave of the backing warp and face weft, a compound fabric structure will be created. With the correct technical parameters and weft selection information, a digital jacquard fabric with a figured double-face effect is produced.

It may be seen from the design principles and methods described above that the key technical problem of structural design in figured double-face fabric has been solved by the layer-combination design method. So long as the technical requirement of designing regular variant weaves and building corresponding weave-databases can be met, the face and reverse sides of a double-face fabric are capable of displaying independent colour and pattern effects in both black-and-white and full colour.

7.5 Design illustrations for full-colour and layer-figured double-face effect fabrics

Two typical design illustrations for figured double-face digital jacquard fabric are put forward with detailed design processes. They describe the design method and highlight the advantages of the layered-combination design mode.

Table 7.4 Technical specification of full-colour figured double-face fabric.

Parameters	
Materials	
Warp	1/166.7 dtex polyester (white)
Weft	1/166.7 dtex polyester (dark/dark/light/light)
Density	
Warp	45 threads/cm
Weft	100 threads/cm
Composition	Polyester 100%
Weave structure	12-thread gamut weaves, 37 grey grades
Design repeat	1248 needles × 4608 fillings
Pattern repeat	22.01 cm (width) × 46.08 cm (length)
Weight	265.8 g/m ²

7.5.1 Design of full-colour figured double-face effect fabrics

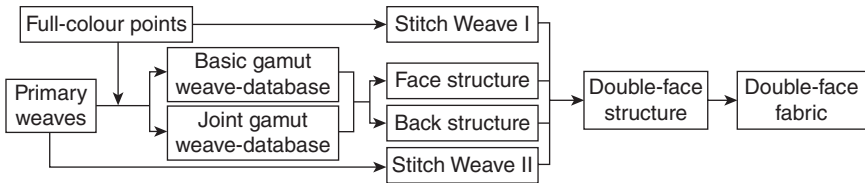
Structural design is the key technique in figured double-face jacquard fabric. The application of digital design technology has laid the foundation for the design of these fabrics, which have a full-colour effect on both sides. In the layered-combination design mode, both sides of a figured double-face fabric are designed by the application of a full-colour compound structure with stitch weaves based on primary weaves and their full-colour technical points respectively. All the threads interwoven in the fabric construction are utilised in expressing a full-colour effect.

Technical specification

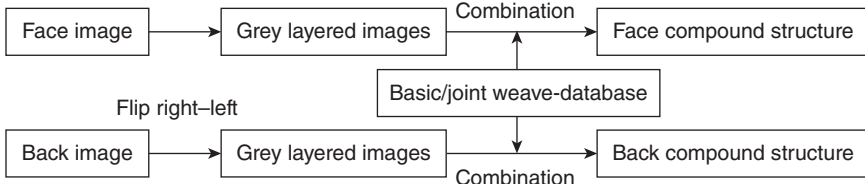
The major technical parameters of full-colour figured double-face fabric are shown in Table 7.4. Both the warp and weft threads were polyester. The fabric was constructed by 12-thread gamut weaves with a lower thread density in the warp direction and a higher thread density weft-wise. As a two-layer structure is necessary for double-face fabric, four weft threads were used for the fabric construction. Their colours were dark, dark, light and light, arranged in the proportion of 1 : 1 : 1 : 1.

Design processes

Fabric with a full-colour effect requires a compound structure on both sides. The key technical point is therefore the design of the stitch weave. This should meet two basic technical requirements: it must be a regular weave



7.14 Design process of full-colour figured double-face jacquard fabric.

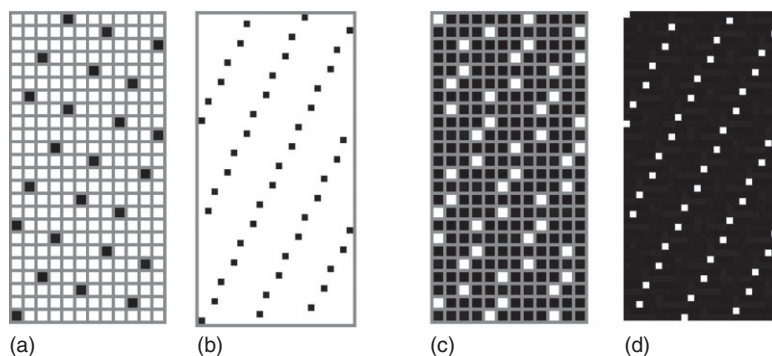


7.15 Structural design of full-colour figured double-face fabric.

that meets the requirements of balanced interlacing for the purposes of mass production, and the full-colour non-backed effect on both sides of the fabric should be kept unchanged when applying the stitch weave. These two requirements are addressed by an appropriately skilled design method for full-colour compound fabric structure. The primary weave and its full-colour technical points are confirmed and form the basis on which the stitch weaves are designed. Because the primary weave and its full-colour technical points remain unchanged, the stitch weaves based upon it must be designed as a regular weave to produce a full-colour effect on both sides of the fabric. The design processes are specified in Fig. 7.14.

The face and backing structures of full-colour figured double-face fabric are compound structures and their design processes are detailed in Fig. 7.15. It should be noted that the design of the face structure is independent of the backing structure. However, the technical parameters of the fabric and the weave-database used in designing the face and backing structures should have only minimal differences. The image applied to both the face and reverse sides is transferred into grey mode through colour separation or de-colourising, and the image used on the reverse side flipped from right to left so that after structural combination the face of image will not be altered. In this particular example, the face image is a portrait while the image on the reverse is a rose pattern.

A 12-thread weave was used to design the full-colour structure and weave-database. Primary Weave I was designed as a 12-thread weft-face sateen with five steps. The starting point of the weave was determined as the lower left (warp, weft) = (1, 1). Primary Weave II was also designed as a 12-thread weft-face sateen with five steps. The starting point of the weave



7.16 Design of stitch weaves. (a) Compound primary weave; (b) Stitch Weave I; (c) compound full-colour points and (d) Stitch Weave II.

was determined as the lower left (warp, weft) = (10, 1). Corresponding full-colour technical points were then set in accordance with the character of the two primary weaves. The primary weaves and their full-colour technical points are the same as those shown in Fig. 7.3. The design of the basic gamut weaves may be based on Primary Weave I and applied to building a related weave-database. Similar joint gamut weaves and their relative weave-databases may be designed based on Primary Weave II.

In order to obtain a good structural combination, the same gamut weaves were applied to the design of both the face and backing fabric structures. The double-face fabric created therefore had the same structural property of balanced interlacing on both sides, although the images on the face and reversed sides varied. As the primary weave and its full-colour points should not change during the course of fabric structure design, the effect of combining the two primary weaves and the two full-colour points should remain constant in the compound fabric structure, even though the images vary on different sides of the fabric. The design of regular stitch weaves can therefore be based on the combined primary weave and full-colour points respectively. Figure 7.16 shows the design diagram, where (a) is the combination effect of Primary Weave I and Primary Weave II, in which Stitch Weave I was designed by reducing the warp interlacing points. The combination effect of the full-colour points devised from Primary Weave I and Primary Weave II is shown in (b). Stitch Weave II was designed by reducing the weft interlacing points. It should be noted that Stitch Weave I is constructed by a backing warp and face weft, whereas Stitch Weave II consists of a face warp and backing weft.

Structure combination and fabric effect

The completion of the design of the face and backing structures and their related stitch weaves is followed by design of the structural combination

for the full-colour figured double-face fabric. The combination method uses a white warp and four weft threads that are arranged into two groups of face and backing threads in 1 : 1 order. The face group threads consist of one group of white warp threads and two groups of weft threads within which the dark and light colours interweave to form the face effect. The backing group consists of one group of white warp threads and two groups of weft threads with a colour similar to that of the face group threads. The relationship between the deployment of the warp and weft and the fabric structures can be seen in Table 7.3. Stitch Weave I is produced from the face warp and backing weft, and Stitch Weave II is generated from the backing warp and face weft. In this design, both Stitch Weave I and Stitch Weave II are employed in the compound fabric structure. The weft selection consists of face weft and backing weft alternately. The corresponding colour effect is dark, dark, light and light.

A compound fabric structure based on the combination relationship shown in Table 7.3 was produced by fixing the starting point so as to combine the face and backing structure with two stitching weaves. Its size is double that of the face/backing fabric structure. This structure is capable of expressing a double-face effect with different images on the face and reverse sides of a fabric in which the grouping threads on both sides vary independently of each other. A fabric produced in this way is shown in Figure 7.17 (and Appendix 3, section A3.8). As a full-colour compound structure meets the technical requirement of balanced interlacing, it is



7.17 Figured double-face digital jacquard fabric.

suitable for mass production. This method for the production of figured double-face jacquard fabric therefore has considerable commercial value.

7.5.2 Design of layer-figured double-face effect fabrics

In addition to the design of full-colour figured double-face fabric, a design variation can be achieved by removing stitch weaves in the layered-combination design mode. Fabric produced by this method has two layered structures in which the face effect of the fabric in each layer may be independently arranged.

Technical specification

Using silk fabric as an example, the major technical parameters are detailed in Table 7.5. The fabric is constructed with a high thread density in both the warp and weft directions by using 24-thread gamut weaves. Pure silk threads were employed in both the warp and weft directions. In a manner similar to the design of full-colour figured double-face fabric, four weft threads were used for the fabric design: these were dark, dark, light and light colours in the proportion of 1 : 1 : 1 : 1.

Design processes

The key technical point of this design example is the pattern design/layout and its related fabric structure design. Because the stitch weaves were removed from the compound fabric structure, an interchanging double-layer structure was employed. Figure 7.18 shows the pattern layout of a layer-figured double-face fabric in which a repeatable image was designed with

Table 7.5 Technical specification of layer-figured double-face fabric.

Parameters	
Materials	
Warp	22.2/24.4dtex × 2 silk (white)
Weft	22.2/24.4dtex × 5 silk (dark/dark/light/light)
Density	
Warp	115 threads/cm
Weft	92 threads/cm
Composition	Pure silk 100 %
Weave structure	16-thread gamut weaves, 53 grey grades
Design repeat	6000 needles × 4800 fillings
Pattern repeat	52.2 cm (width) × 52.2 cm (length)
Weight	126.6 g/m ²

Pattern 4 Face down Backing	Pattern 1 Face up Face	Pattern 2 Face up Face	Pattern 3 Face down Backing
Pattern 2 Face up Face	Pattern 3 Face down Backing	Pattern 1 Face up Backing	Pattern 4 Face down Face

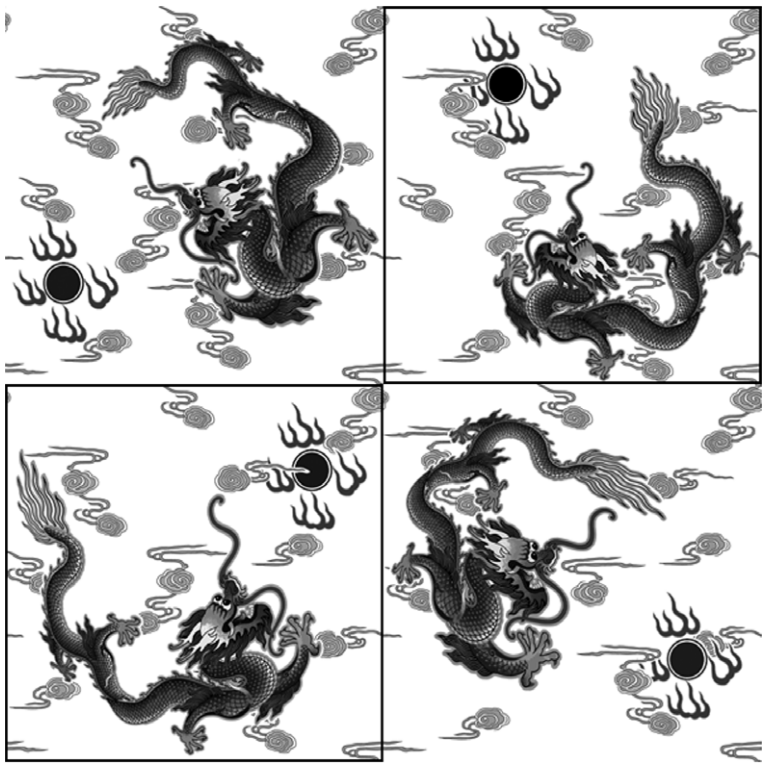
7.18 Pattern layout of layer-figured double-face fabric. (a) Pattern layout of face layer; (b) pattern layout of backing layer.

four subsidiary patterns. In accordance with the design requirements, the four patterns with a two-layer structure were arranged into varied relationships between the face and back. There are four possible relationships between the face layer and backing layer, viz. face up and face down, face up and face up, face down and face down, and face down and face up (see Fig. 7.18).

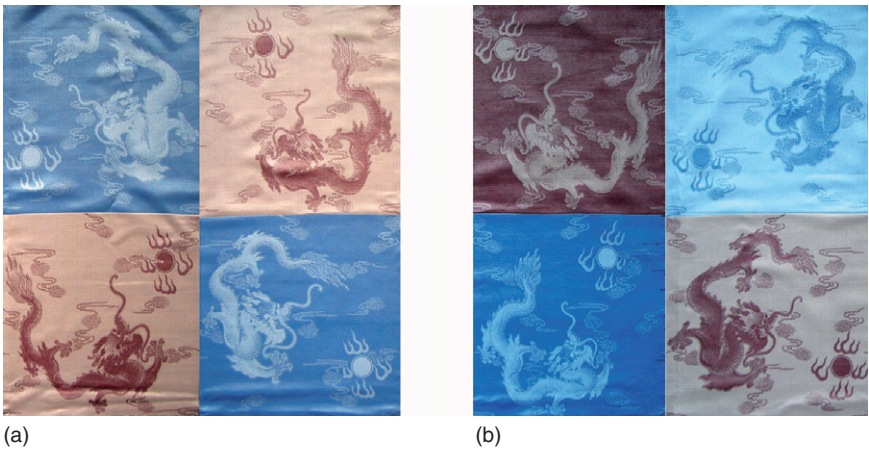
The interchanging double-layer structure requires the face and backing layers to alternate in the pattern layout. This performs the function of a stitch weave in the compound fabric structure. The gamut weaves and weave-databases used in the design of full-colour figured double-face fabric may also be applied to the design of layer-figured double-face fabric. The face pattern effect is designed with the pattern arrangement described above (see Fig. 7.19). Four subsidiary patterns are integrated to form a repeated image and the maximum grey-scale in each pattern is 53 grades.

Fabric effect

Based on the combination relationship shown in Table 7.3, four individual compound fabric structures with four subsidiary patterns were generated by fixing the starting point to make four combinations of the face and backing structure. The final compound fabric structure therefore had four repetitions of each subsidiary pattern. By using a weft selection from the technical specification, a layer-figured double-face fabric was produced (see Fig. 7.20 and Appendix 3, section A3.9). The face and backing layers of this fabric were exchanged, with each layer having an individual pattern effect. The colour and pattern effect in each layer may be altered by changing the pattern design and coloured threads.



7.19 Pattern design of face side in layer-figured double-face fabric.



7.20 Effects of layer-figured double-face digital jacquard fabric.
(a) Face side; (b) reversed side.

7.6 Conclusion

Based on the design examples described above, the main findings on both figured shot-effect fabric design and figured double-face fabric design may be summarised as follows: figured shot-effect fabric, an innovation in jacquard textiles, has been successfully created by using lustre threads of contrasting colour in a full-colour compound structure and combining a digital grey image with its negative image. This meets the technical requirements for the mass production of jacquard textiles. If paired juxtaposed threads have the same floating length, the fabric effect will be the same as that of traditional shot-effect fabric constructed with a plain weave. If the threads have different floating lengths, a figured effect will be produced. When paired lustre threads of contrasting colour are arranged in juxtaposition, the resultant fabric displays both contrasting figure and colour effects. If a full-colour compound fabric structure is applied, it will create a figured shot-effect fabric with a colour shading effect similar to that of a printed textile. Because it is now possible to use digital images in the design of shot-effect fabric, the complex procedures of image modification are removed and the design efficiency is greatly increased.

The design of figured double-face fabric differs from that of simulative and figured shot-effect fabrics. It employs a double-layered fabric structure of layered-combination design in which two groups of threads are used on the face and reverse sides, together with a full-colour compound structure and appropriate stitch weaves. This fabric meets the technical requirements for the mass production of jacquard textiles. The stitch weave must be regular if a good covering effect between the face and backing layers is to be obtained whilst still maintaining balanced interlacing. The major technical problems of stitch weave design are overcome by using a full-colour compound structure that enables a full-colour effect to be displayed on both sides of the fabric. As the woven patterns on the face and reverse sides are individually constructed and are independent of each other, the pattern and colour effect on each side of a figured double-face fabric can be varied independently with separate colour threads. Interesting effects in a layer-figured double-face fabric may be produced by removing the stitch weaves. Their patterns in the face layer and backing layer may then be independently altered.

It may be concluded from the design examples described above that innovative design in figured shot-effect and figured double-face fabrics offers technical, aesthetic and commercial values superior to those that are possible in printed fabrics. The layered-combination design mode has been shown not only to simulate, but to be capable of producing, innovative images that were not previously possible. The findings of this book have broadened the creative scope of jacquard fabric design and the potential commercial applications are a fertile field for future research.

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Applications of digitally designed jacquard textiles

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Abstract: This chapter presents case studies of existing products and potential products in which digitally designed jacquard textiles may have applications.

Key words: digital, jacquard, woven, applications.

8.1 Introduction

Because jacquard fabrics consist of threads that may be interwoven in a variety of constructions, the images produced have a richness of texture and tactile effect that is unique to woven technology, e.g. the shot effect described in Chapter 7. Conventional jacquard images produced and/or created on woven textiles are often crude and limited in colour due to their bi-axial constraints and complex warp–weft constructions. They are therefore less effective in creating or reproducing photographic images and picturesque effects, which require smooth gradations of colour. The digitalised jacquard fabrics described in this book overcome these constraints and are capable of producing effects that are not available in woven textiles.

No special jacquard machinery is required for the mass production of full-colour digital textiles by this method. The method is readily compatible with most, if not all, existing jacquard machines, thus conferring a major commercial advantage. The variety of yarns and colours extends the range of effects and properties available for different product categories, e.g. architecture, automobiles, fashion, home furnishings, installation. Four case studies of applications of digital jacquard textiles are described in this chapter.

8.2 Case study 1: digital images on bags

Air pollution is a global problem and is the subject of international cooperation and conflict. Countries, such as China, that have high numbers of motor vehicles and use large quantities of coal are the most severely affected. Air that contains a high level of chemical pollutants presents a risk to health and it is anticipated that the demand for cleaner air will continue to grow, both from the general public and from the increasing numbers of people who are allergic to polluted air. Results of a pilot survey carried out in China showed the general public to be receptive to the concept of paying for clean air and take-away compressed air in much the same way as they



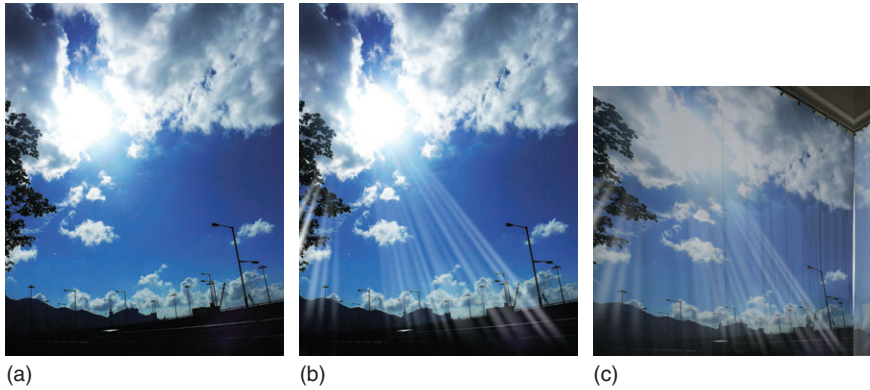
8.1 A series of bags with images of Huangshan in full-colour digital jacquard textiles.

pay for gas, electricity and water. In 2008, a project entitled ‘Fengqi’ (Yu, 2008) aimed to supply compressed clean air from unpolluted regions to commercial and residential areas in accordance with the Ambient Air Quality Standard. The first trial run identified clean air from the Huangshan region in Anhui, China and aimed to provide take-away clean air in compressed containers and portable air bags bearing an image of the place from which the air was obtained.

The examples in Fig. 8.1 show a range of bags made for bottles of compressed fresh air from Huangshan (Yellow Mountains) in Anhui, China – an area well known for its scenic and unpolluted environment. To reproduce this scenery, digital images of Huangshan were woven into jacquard textiles to form the fabric of the bags. Full-colour digital jacquard technology enabled the reproduction of these intricate scenic images using only four yarn colours: magenta, cyan, yellow and black. The fabric production process took less than a week, making it possible to put the bags on the market in a relatively short period of time. Figure 8.1 shows the bags in full-colour digital jacquard textile.

8.3 Case study 2: curtains

Curtains consisting of images of a cloudy sky were produced using full-colour digital jacquard technology and shape memory fibres (SMF). The

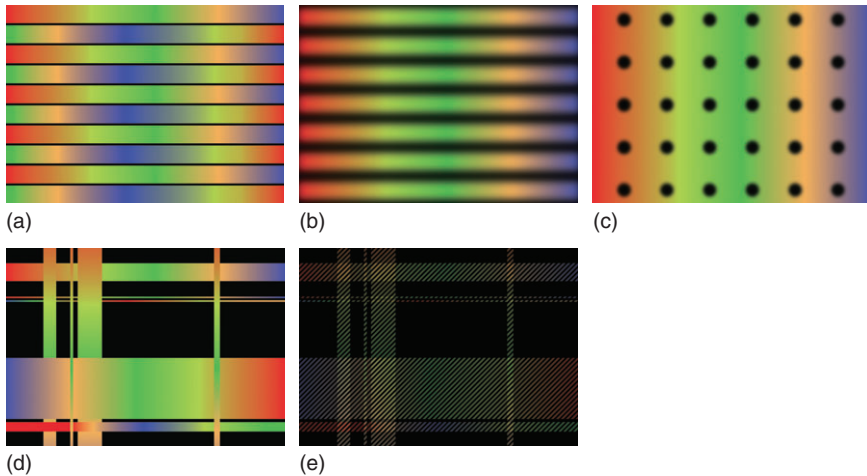


8.2 A design and its effect for the project 'Morning has broken'.

shape memory fibres enable the texture of the cloth in which they are woven to open up when the temperature rises. The consequent effect is of sunlight shining through the clouds in the morning as these areas of threads opened up in response to sunlight. Figure 8.2 shows the design and effects. Image (a) shows an image of white clouds in a blue sky, woven in cotton and shape memory fibre and produced by full-colour digital jacquard technology, (b) shows the effect when designated portions of the clouds open up in response to sunlight, and (c) shows the effect when curtains made of the cloth are hung in a room.

8.4 Case study 3: rainbow fabrics

As woven fabric is more expensive than printed textiles, it has long been a challenge to produce a woven colour spectrum with a smooth gradation of colour. Such a spectrum has been made possible by full-colour digital jacquard technology, and utilising its capacity for the seamless gradation of colour, a range of plaids were successfully produced by Ng and Yu (2009) (see Fig. 8.3). Image (a) shows various rainbow stripes. Image (b) develops image (a) by blurring the stripes. The blurred effect is made possible only by the use of digital jacquard technology and could not have been obtained by conventional woven textile methods. Image (c) explores the rainbow and blurring effects further with the addition of circles. Image (d) shows rainbow stripes in a plaid design and image (e) shows an addition of a diagonal woven plaid effect superimposed on the rainbow stripes. The addition of black to the design intensifies the rainbow colour effect. These fabrics can be made into various commercial products, including, but not limited to, head bands, fashion bags, upholstery, curtains and table cloths.



8.3 Varied designs of rainbow colour stripes produced by full-colour digital jacquard technology.

8.5 Case study 4: seamless woven garments

A research project on the creation of seamless woven fashion (SWF) as a hybrid of the new flexible layered jacquard textile structures and clothing construction was undertaken in 2006 by Wang and Ng. Developments in computerised jacquard weaving technologies and the introduction of special stretch materials and three-dimensional woven structures have provided new opportunities for SWF. The design mode, which includes systematic principles and practical methods for advanced jacquard weaving, was reinvented for this project to enable the design, realisation and presentation of various forms of SWF.

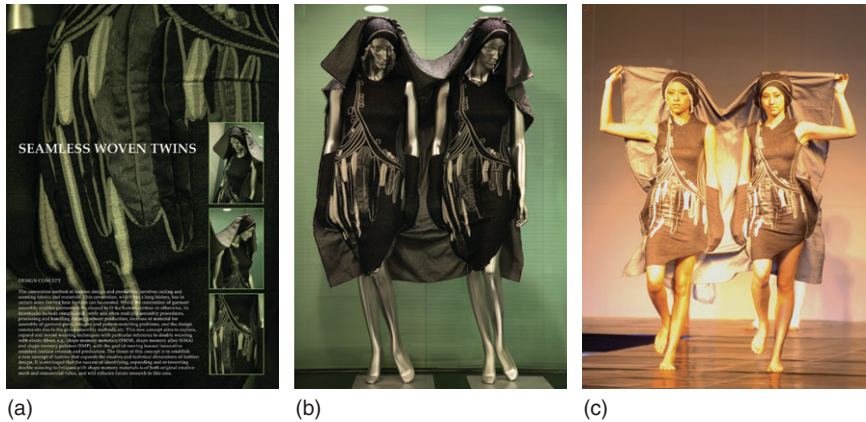
Research into seamless or full-fashioned technologies in fashion has increased considerably during the last five decades. Since the 1960s, seamless knitted garments have been successfully developed using advanced knitting machines and sophisticated design systems. However, inadequate design approaches and undeveloped biaxial weaving manufacturing systems have impeded the development of seamless woven garments. The unitary two-dimensional design mode of conventional weaving systems is directed towards laminar fabrics and has been unable to meet the changing needs of contemporary fashion.

The nature of the research is exploratory and practice-led. The theoretical deployment of SWF and its practical realisation were conducted in three stages. The first stage, which was based on the requirements of fashion design and the nature of jacquard woven textile design, identified

the crucial issues for establishing an integrated design mode for SWF. In the second stage, the design mode was explored and evaluated from theory to practice in two experiments with respect to 'sectional fabrics' and 'forms' of SWF. These refer to the two essential components of sectional and overall construction. The experimental results were analysed to identify the relationship between the woven design elements and the properties of the SWF examples. Both the technical features and the aesthetic merits of the shaped woven textiles or fashions created by the new design mode were systematically considered. In the third stage, applications of the proposed design mode were demonstrated by a series of examples presenting the diverse creative effects of SWF, which confirmed the efficacy of the design mode.

This study combined new weaving technology with jacquard textiles for the production of seamless woven fashion, thus making it possible to design and manufacture a variety of fashion products directly from the weaving system. The innovative integrated design mode was used to generate three-dimensional SWF designs through a new combination of the flexible properties of stretch materials and the advanced complex structural designs of the modern jacquard system. The research results highlighted the original successful concepts, principles and methods of SWF designs, which have gave rise to a number of original effects in innovative woven fashion textiles. Research contributions include both the theoretical and practical elements of the designs. The provision of detailed design illustrations, including technical settings, design parameters and programming methods, may be considered as specific design databases or as references created for ease of reproduction in extended and new design ranges. The knowledge gained from this research work has contributed to future research in the area and to the end-products designed and manufactured by these concepts and processes. The major significance and value of the project lies in its provision of an integrated design mode for the concurrent development of woven textiles and fashion design. The innovative features of seamless woven fashion have laid the foundation for the development of three-dimensional design systems for future advances in SWF. They also have the potential to improve productivity and to develop new commercial dimensions in design and manufacturing. The study also serves as a valuable reference for practice-led design research. By combining knowledge of jacquard woven textiles with fashion design, the research increases the creative potential of woven textiles produced by modern technology. It is envisaged that the knowledge gained from this work will contribute to future research and development in the theory and practice of designing and manufacturing fashion products.

'Weaving Seamless Bags' by Wang and Ng (2006) has won several design awards including the Overall Grand Award at the 8th International



8.4 Design and details of the Seamless Woven Twins on display and in a catwalk show.

Foundation of Fashion Technology Institutes (8th IFFTI) Design Competition held in June 2006 at North Carolina State University, USA. Figure 8.4 illustrates details of the work and its modelling on the catwalk.

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Current issues and future trends in digital jacquard textile design

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Abstract: This chapter summarises the investigative work involved in the preparation for this project, including a summary of design creations and the major findings obtained. Outstanding problems and recommendations for further research work are also presented.

Key words: digital, jacquard, design, design theory.

9.1 Introduction

This chapter summarises the research to date, the results and insights obtained and the limitations and implications for future research. The present study proposed an innovative design concept named ‘layered-combination design mode’ with the aid of digitisation technology that is particularly suitable for the creation of digital jacquard. The study explores the major technical issues of this design mode. By merging design theory with practice, the innovations in design concepts, principles and methods proposed in this book have been validated and shown to have positive creative and commercial value. Results of the study laid a solid foundation for further research into digital jacquard textile design. In this chapter, the key technical points of the design research are summarised and the major characteristics of design innovation in their theoretical and practical aspects are identified. The values and significance of the results obtained in the study are highlighted and the limitations and recommendations reported.

9.2 Advances in theory

Research in the field of digital jacquard textile design integrates the basic principles of fabric science, colour science, and computer science. It departs from the ancient traditional concepts and methods of jacquard fabric design in which colour expression was limited. The present study merged digital design concepts with jacquard textile design and has made some valuable theoretical and practical contributions to their design and production. Table 9.1 summarises the characteristics of traditional jacquard textiles and the digital jacquard textiles proposed in this book.

Table 9.1 Distinctions between traditional and digital jacquard textile design

	Identities/characteristics	
	Traditional jacquard textile	Digital jacquard textile
Design concept	Single-plane design mode	Layered-combination design mode
Design principles and methods	One-to-one corresponding	From colourless mode to colourful mode
Weave design	Simple weave and complex weave designed by single weave design mode	Gamut weaves and weave-database
Fabric structure	Simple weave and/or complex weave	Single-layer fabric structure and compound fabric structure
Colour mixture theory	Experience-based colour consideration and colour table	Juxtaposition colour mixture
Colour number	Less than 100	Up to mega level
Colour effect	Individual colour with distinctive colour borders	Colour shading effect without obvious colour borders
Fabric effect	Mechanical effect imitating objective pattern	Variable digital effect with digitisation structure

Established theoretical research laid the foundations that guided the design practice and applications in the study. It assisted in identifying the factors in design concepts, principles and methods that differ from those of traditional jacquard production. For clarity, the theoretical innovations of digital jacquard textile design are summarised below.

9.2.1 Design concepts

The traditional jacquard design concept is based on a single-plane design mode that limits the scope for innovative design. Before the advent of CAD systems, little progress was made in developing the traditional single-plane design mode due to its complex design method and fabric construction. Despite the introduction of the jacquard machine and the powered weaving loom, there was no significant breakthrough in the creative aspects of fabric production and the only advances were in design and production efficiency. Taking inspiration from digital image design, the present research proposes a new design concept of ‘layered-combination’ as a substitute for the traditional single-plane design mode of jacquard textile design. The layered-combination method makes it possible to design digital jacquard textiles

that cannot be obtained by any other methods of design and production. The advent of a digital era in jacquard textiles has significantly enhanced the creative scope of textile design.

9.2.2 Design principles and methods

The design principles and methods for digital jacquard textiles also differ from those of traditional jacquard. It is evident that fabric structure is the most important aspect of the design. The structural design of traditional jacquard fabric is a 'one-to-one corresponding' principle in which simple and complex weaves in the fabric structure are individually designed to imitate the corresponding colour effects of the pattern. The method of replacing individual colours by specific weaves is complex and inefficient. Jacquard fabric produced by this method is also limited in its colour expression.

The study improved upon the traditional design concept by means of the layer-combination design mode. The alternative design principles and methods proposed in this book consist of both colourless and colourful design modes. The design of colourless digital jacquard is based on the colourless mode (digital grey colour theory) and the traditional single-layer woven structure, in which the one-to-one corresponding principle is still utilised to design a single-layer fabric structure. However, gamut weaves are used in place of a single simple or complex weave. In colourful digital jacquard design, selected single-layer structures are combined to produce a compound fabric structure in which the number of mixed colours exhibited on the face of fabric is increased to a very high level.

9.3 Advances in applied research

The major research findings and contributions to digital jacquard design and production that are the subject of this book may be classified as: (i) structural design, (ii) colour mixture theory, (iii) design practice in the colourless mode, and (iv) design practice in the colourful mode.

9.3.1 Structure design

The design of fabric structure is the key process in jacquard textile design. A considerable amount of practical research has therefore been devoted to creating a new method of designing fabric structures for digital jacquard textiles. Significant results include an optimal design method for gamut weaves that addresses the technical requirements of balanced interlacing; three types of compound structures – backed compound fabric structure, partial backed fabric structure and non-backed (full-colour) compound

fabric structure; and the single-layer and compound fabric structural designs under the layered-combination design mode in both the colourless and full colour modes. The original design method of full-colour compound structure described in this book is particularly noteworthy. This innovation may be regarded as one of most important breakthroughs in the field of jacquard textile design, enabling the expression of an accurate high level colour effect.

In summary, practical research into structural design has resulted in the replacement of the traditional single-plane design mode with the layered-combination design mode. The design and production of digital jacquard fabric has been revolutionised and will lead to a new era of digitalisation.

9.3.2 Colour mixture theory

The colour mixture theory of woven fabrics differs from that of printing and screen display. The technical requirements of design and production in the traditional plane mode permit only a limited colour effect with little reference to colour mixing properties. However, when the layered-combination design mode is used, the number of available mixed colours is increased to a very high level. The colour mixture effect *per se* therefore becomes a determining factor in the overall aesthetic appeal of digital jacquard fabrics.

The research investigated the phenomenon of mixed colour effect and presented the following findings. (i) Due to various factors which affect colour performance, there is a disparity between the theoretical and practical aspects of colour. The performance of colour mixture digital jacquard design in the layered-combination design mode is basically in line with the juxtaposed optical colour mixture. (ii) Digitised structural design in jacquard textile requires conversion between the digital colour modes. Seamless conversion from the digital colours of digital images to the digitised structure of jacquard fabric was realised by combining different colour modes of digital images, e.g. CMYK digital colour processing. (iii) This design method for full-colour compound structure digital jacquard fabric is capable of expressing an accurate mixed colour effect with a very high number of colours. (iv) Both simulated and innovative effects in digital jacquard textiles can be obtained through the use of primary coloured threads. (v) Practical research into the colouring phenomenon of digital jacquard fabric shows the distinctive quality of the colour mixture theory. It also offers an original design concept of commercial and artistic value for structural digital design with reference to colour science and primary colour theory.

9.3.3 Colourless and colourful digital jacquard textile design

Certain challenges encountered during the design process are posed by a lack of prior knowledge and experience in using the layered-combination design mode. A study of design practices in the colourless and colourful design modes was conducted to identify technical problems that might arise and to establish ways in which they could be resolved. Some useful findings gained from the practical research are summarised next.

In addition to the technical requirement of balanced interlacing in colourless digital jacquard fabric, a disparity between the black-and-white effect of gamut weaves and that of the fabric produced must be minimised. This is addressed by tailoring the design of the gamut weaves in accordance with the objective image. In colourful digital jacquard textiles, the compound structure of the fabric, which is created by combining single-layer fabric structures designed with standard gamut weaves, is capable of expressing a high level of mixed colours on the face of fabric. However, broken streaks appeared in the structural design with consequent colour deviation and a deleterious effect on the simulative effect design. The full-colour compound structure design method described in this book enables the production of digital jacquard fabric expressing a fine colour shading effect. This makes possible the simulation design of digital jacquard textiles with accurate colour reproduction.

9.3.4 Digital jacquard fabric design

Unlike jacquard textiles made by the traditional plane-design mode, digital jacquard textiles produced by layered-combination design have the significant advantages of high level colour expression and fine colour shading. These two features open new creative horizons in jacquard textile design. The designs introduced in Chapters 6 and 7 illustrate the simulative and innovative effects that are made possible by these technical innovations. The research introduced three methods for the design of black-and-white simulated effect digital jacquard fabric: single-layer fabric structure, compound fabric structure (a design method which de-colourised true-colour simulative design), and a method of designing colourful simulative effect jacquard fabric by means of double colour separation based on CMYK primary colours. This book proposes two innovative effect design methods. One is figured shot-effect jacquard fabric that can simultaneously display contrasting figure and colour effects on the face of fabric. The other is figured double-face effect jacquard fabric that shows full-colour figured effects independently on both the face and reverse sides of the fabric. All

these digital jacquard design creations may be applied to fashion and interior design. The jacquard fabrics proposed in this book, which are designed through digitisation technology and the layered-combination design mode, signal a new era in jacquard fabrics in which technical and artistic merit are optimised. More commercial designs with pure silk are shown in Appendix 3, in Section A3.10.

9.4 Current limitations and future research

The layered-combination design mode proposed in this book has been developed through theoretical and practical research and by the creation of new designs. It has been shown to advance design innovation in jacquard fabric. However, this new design concept is still in its infancy and further research is necessary to extend the creative and technical boundaries of digital jacquard textile design and production. It is envisaged that results of this study will promote further research.

9.4.1 Limitations

While the study has made significant contributions to digital jacquard textile design and production, there have been certain constraints, which are listed below.

1. As previously described in the consideration of practical research into structural design, there are several methods by which gamut weaves with single-layer fabric structures may be designed. The present research adopted a typical design method. If time had permitted, it would have been desirable for further experiments to have been undertaken on other structural design methods so that a wider range of results relating to the relationship between the fabric structural design method and the final fabric effect could have been obtained.
2. Due to the differences in colour-mixture theories between woven fabric and other colouring means, such as additive or subtractive colour mixture, there is no single colour mixture principle suitable for digital jacquard fabrics designed by the layered-combination mode. The colour reproduction of true-colour simulation design could not accurately simulate that of the original image. In particular, the black colour effect generated by colour mixing is unsatisfactory. More time is needed to further investigate and formulate the principles for colour reproduction in jacquard textiles.
3. Although several specimen images were used to illustrate various novelties, the scope of the experiments, in terms of fabric structure and material, remained relatively narrow.

4. As the layered-combination design mode is a new concept in jacquard design and production, there are no CAD systems designed for this purpose. The design creations presented in this book integrated several CAD systems from a variety of design fields.

9.4.2 Future research

The innovative design concepts, principles and methods described in this book have been validated. It is envisaged that research into digital jacquard textiles produced by the proposed layered-combination design mode may be further developed in the following directions:

1. To further explore the relationships between fabric structure and effect under the layered-combination design mode.
2. To further experiment with the design of gamut weaves and the corresponding weave-databases by other design methods.
3. To further study colour-mixture theory, in particular, the relationship between colour appearance and digitalised structure in the simulative and innovative effects of digital jacquard textiles.
4. To further explore the potential applications of the simulative and innovative effects of digital jacquard textiles with different design methods and materials.
5. To design and enhance CAD system interfaces for the design and production of complex digital jacquard textiles using the proposed layered-combination design mode.
6. To conduct future research on intelligent jacquard fabric design system (IJFD) based on the layered-combination design mode.

9.5 References and further reading

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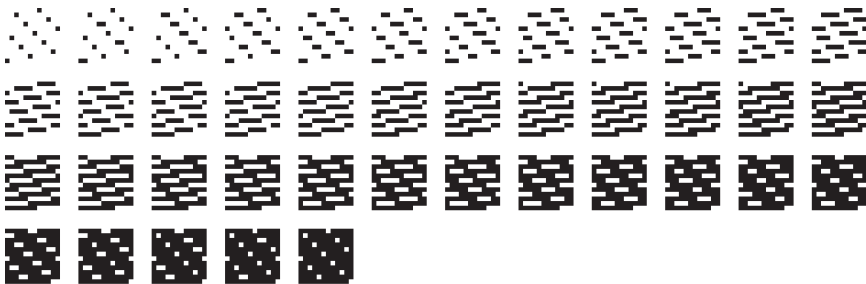
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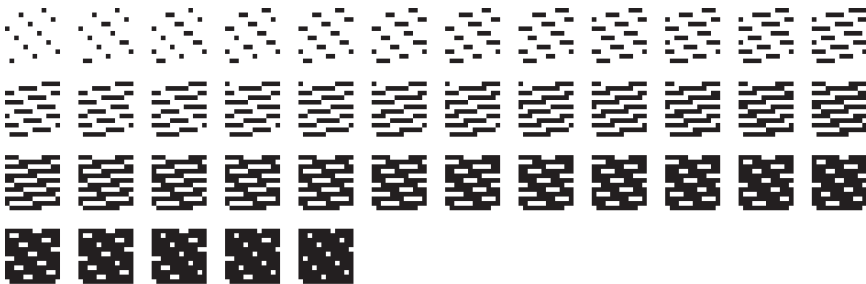
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Appendices

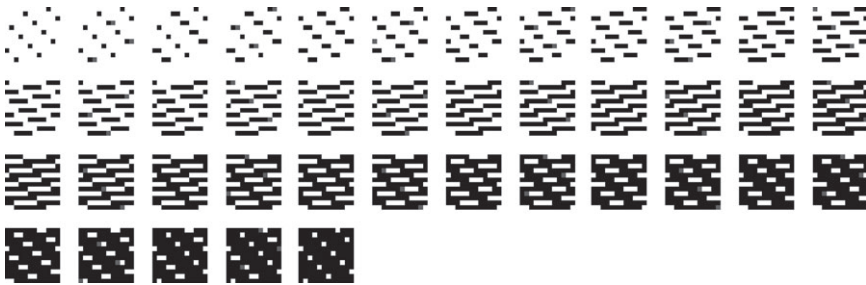
**A1.1 Gamut weaves and weave-databases for
12-thread satin**



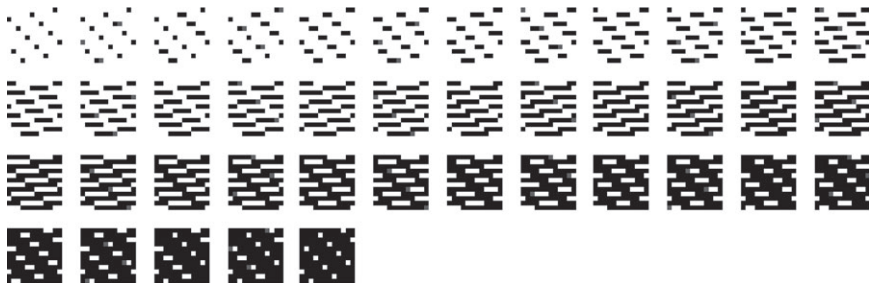
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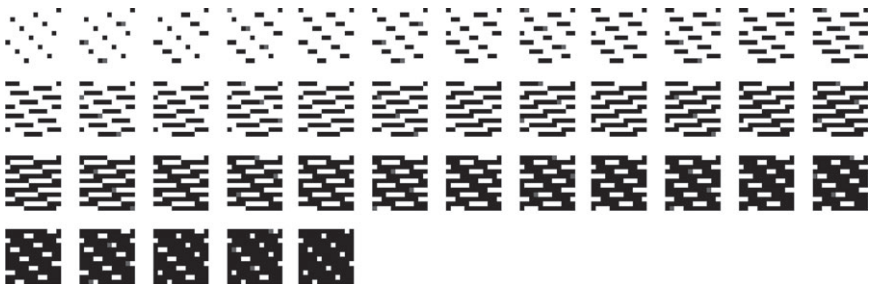
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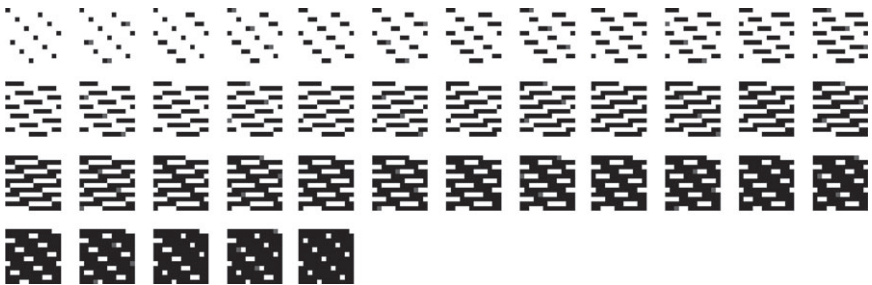
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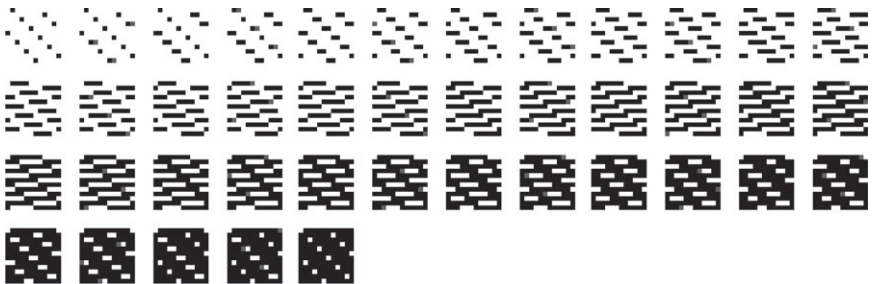
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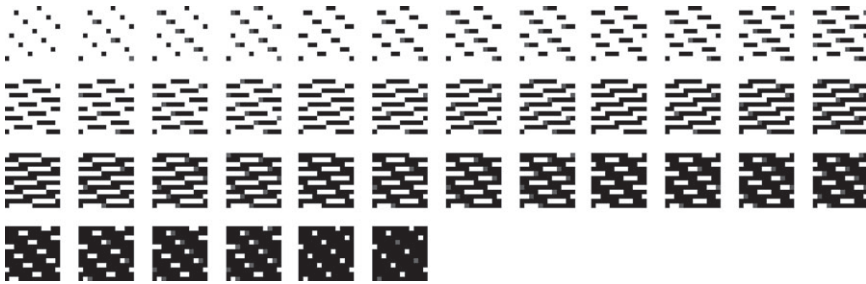
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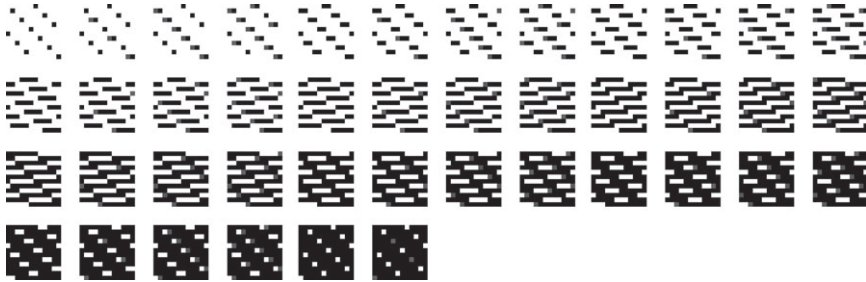
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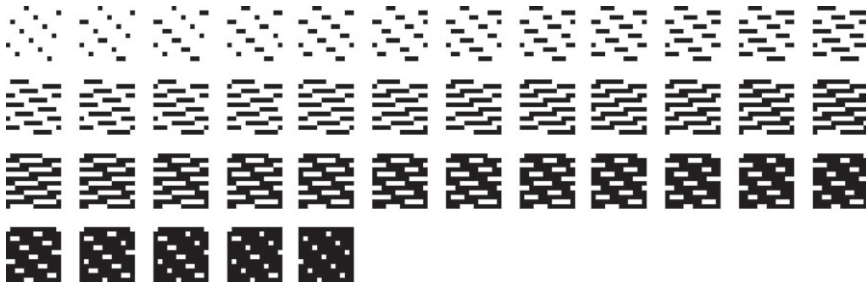
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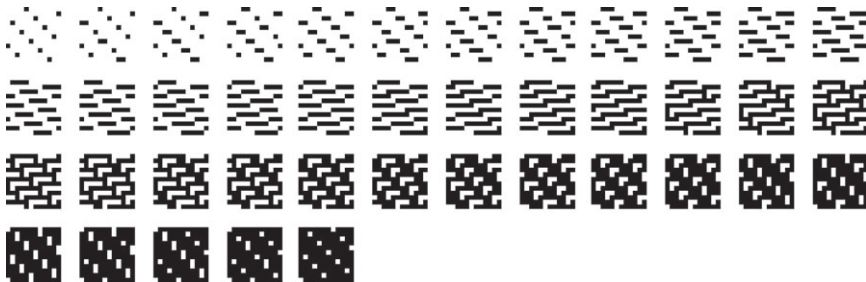
(h) N12-3w-z41



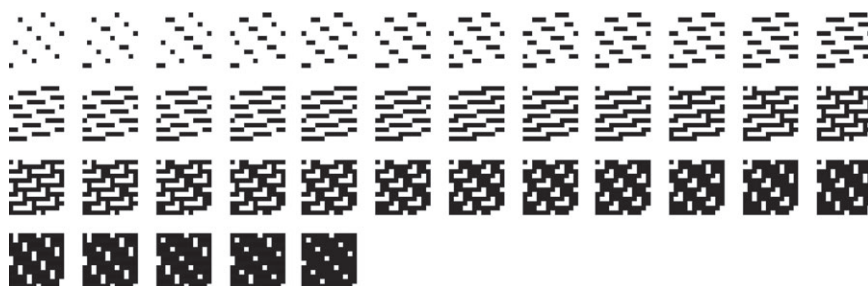
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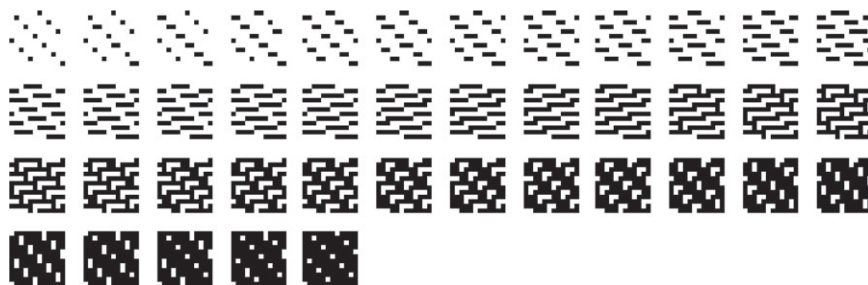
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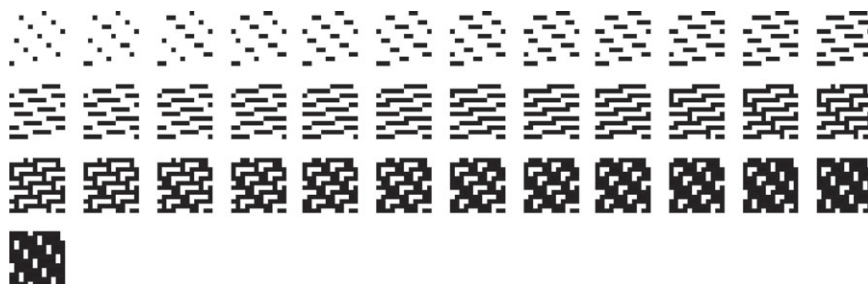
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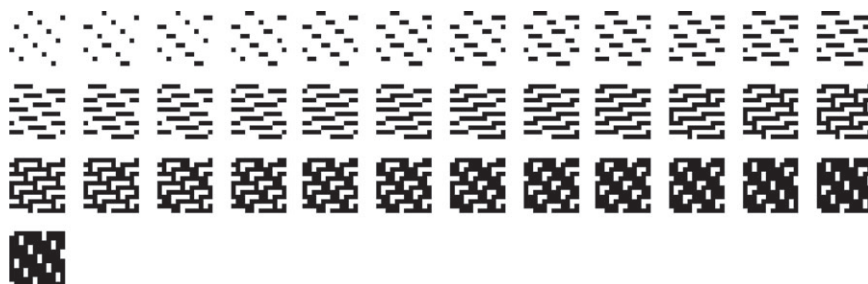
(l) Ac12-3w-j41



(m) Ac12-3w-j41-11

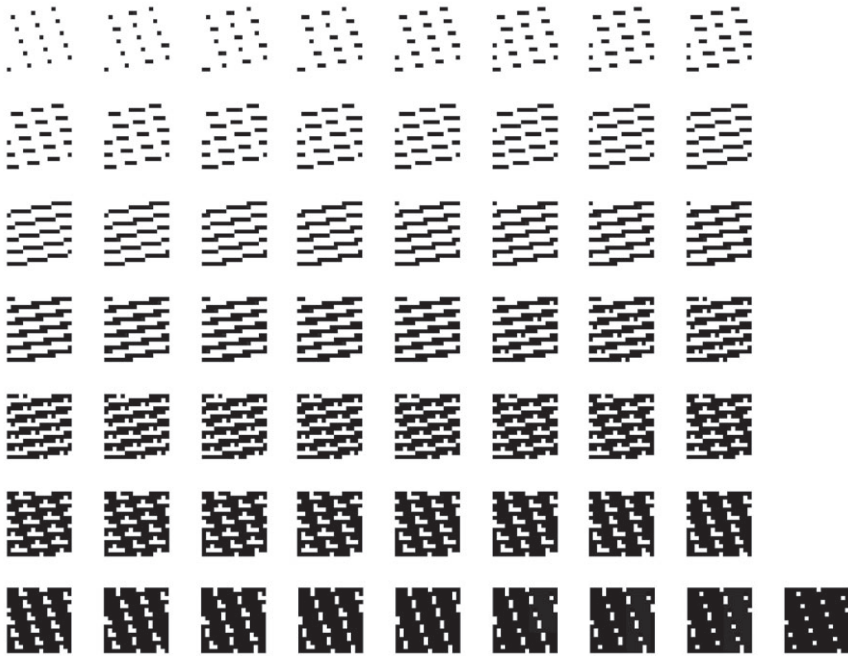


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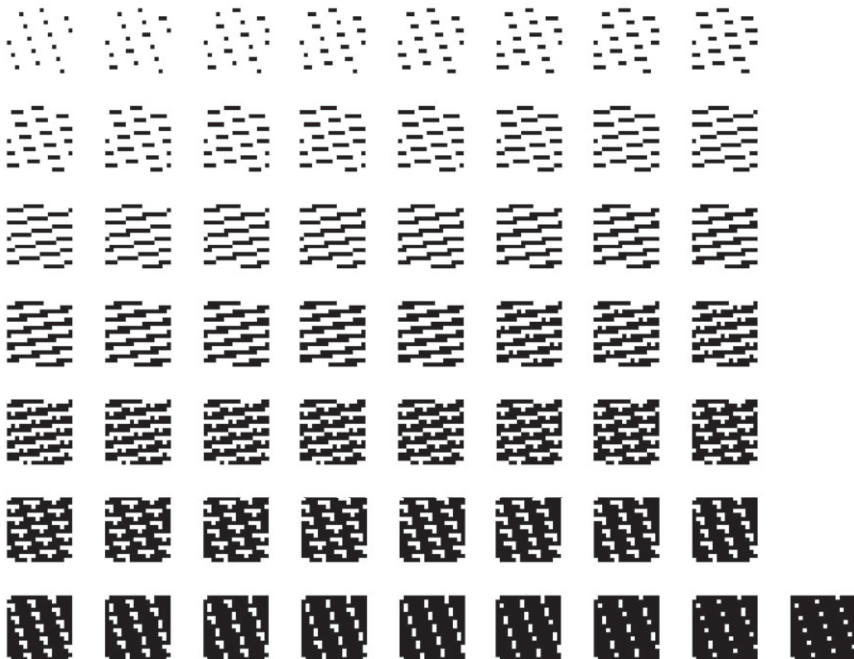


(o) Ac12-3w-z-y41-9

A1.2 Gamut weaves and weave-databases for 16-thread satin

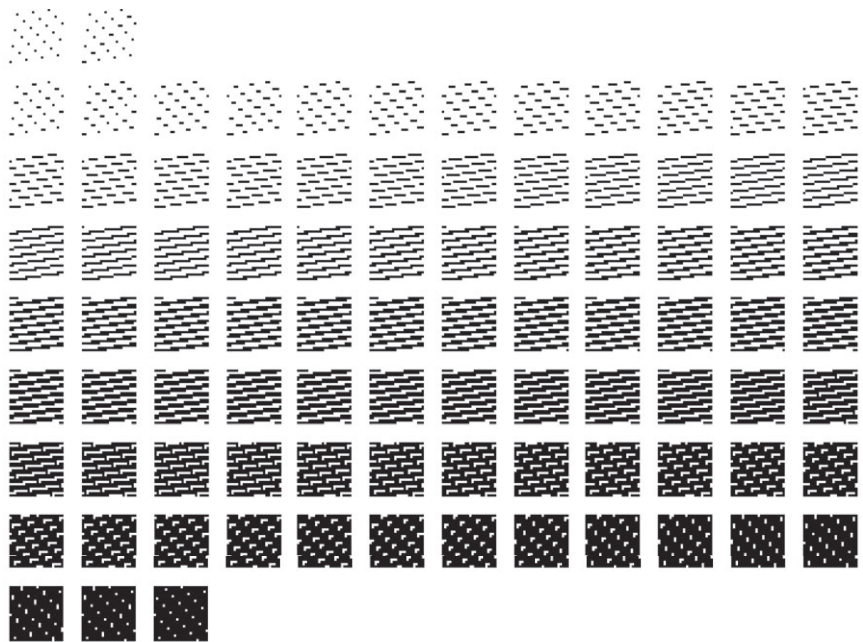


(a) C16-4w-j53

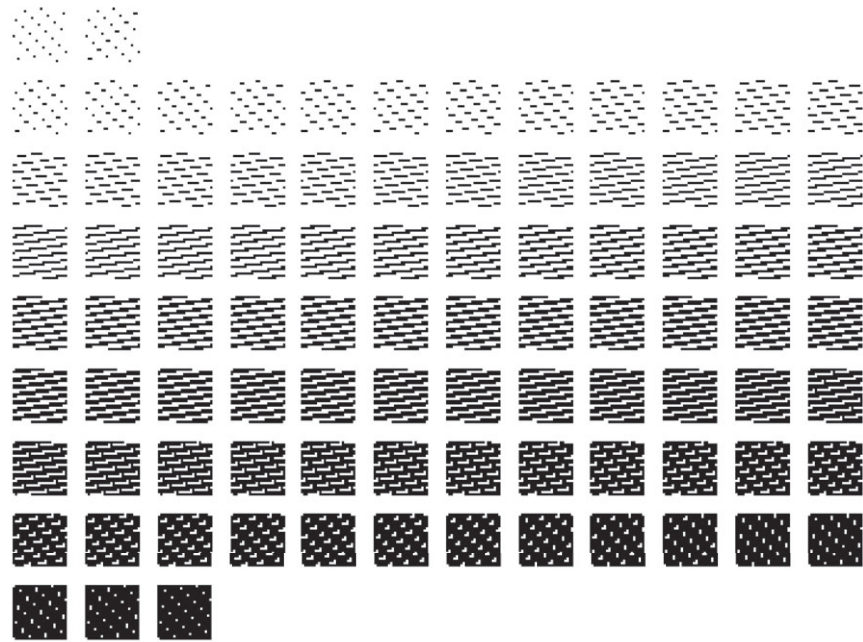


(b) C16-4w-j-z53

A1.3 Gamut weaves and weave-databases for 24-thread satin



(a) C24-7w-j89-y-z



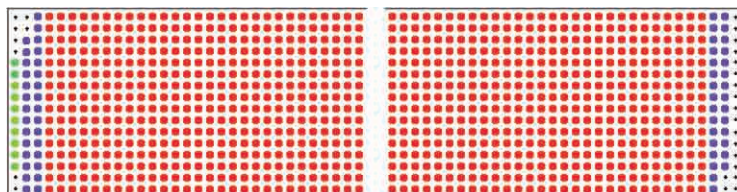
(b) C24-7w-j-z89-z-y

Appendix 2

Technical specifications for jacquard textiles

A2.1 Fabric technical specification with lower warp density

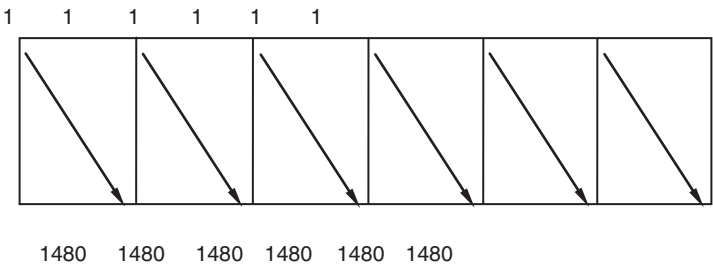
Weaving parameters			
Needles (figuring)	1480	Reed size	11.25 dents/cm
Hook-harness	1–6 (lift)	Reed width	144 cm
Warps in mounting	8800 threads	Denting (per dent)	4 threads
Harness-WARP	1–1 (lift)	Weft pickers/ needles	8
Major fabric parameters			
Warp (fineness)	111.1–166.7 dtex	Weft (fineness)	111.1–333.3 dtex
Fabric width	132.06 cm	Weave repeat	12–16 threads
Selvage width	1 × 2 cm	Gamut weaves	53
Warp density	45 threads/cm	Fabric weight	200–350 g/m ²
Weft density	45–120 threads/cm	Weft groups	1–4
Pattern/structure design			
Pattern repeat	22.01cm (width)	Max. grey-scales	53
Colour fringe	Free drawing	Float cutting	Free drawing
Point paper	48 × 48		
Software applied	Photoshop cs/EAT Germany/Jcad China		
Needles' layout of jacquard machine (Staubli CX870 1248/1344)			



Stop roll: 5,6. Colour selection: 7–14. Selvage: 19–48/1297–1326. Figuring: 49–1296.

(Continued)

Harness mounting



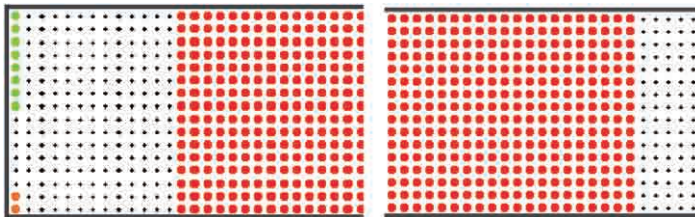
Warp threading From back to front/left to right

Supported by the Weaving Laboratory of ITC, The Hong Kong Polytechnic University.

A2.2 Fabric technical specification with higher warp density

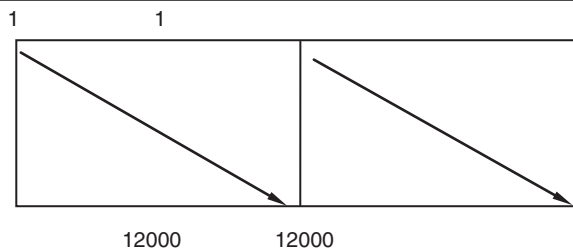
Weaving parameters			
Needles (figuring)	12000	Reed size	28.8 dents/cm
Hook-harness	1–2 (lift)	Reed width	216 cm
Warps in mounting	24000 threads	Denting (per dent)	4 threads
Harness-warp	1–1 (lift)	Weft pickers/ needles	8
Major fabric parameters			
Warp (fineness)	44.4–55.6 dtex	Weft (fineness)	44.4–166.7 dtex
Fabric width	210 cm	Weave repeat	16–24 threads
Selvage width	Nil	Gamut weaves	85
Warp density	115 threads/cm	Fabric weight	122–161 g/m ²
Weft density	90–200 threads/cm	Weft groups	1–4
Pattern/structure design			
Pattern repeat	105 cm (width)	Max. grey-scales	85
Colour fringe	Free drawing	Float cutting	Free drawing
Point paper	48 × 48		
Software applied	Photoshop cs/EAT Germany/Jcad China		

Needles layout of jacquard machine (Staubli LX3200 12000/12288)



Stop roll: 15,16. Colour selection: 1–8. Figuring: 209–12208.

Harness mounting



Warp threading From back to front/left to right

Supported by Zhejiang Sci-Tech University and Babei (China) Garment & Ornaments Co., Ltd.

A3.1 Design creation with smooth colour shading effect (lower warp density)



A3.2 Design creations with colourful simulative effect (lower warp density)

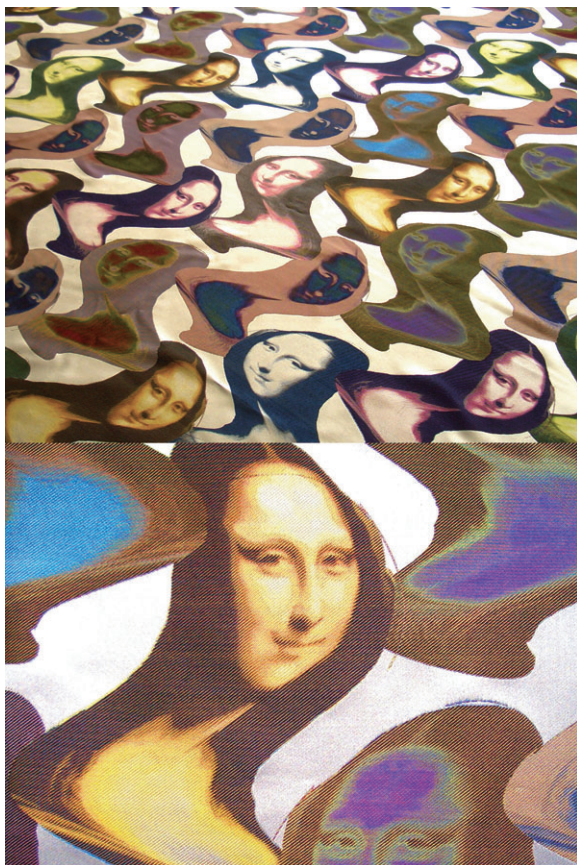


(a)

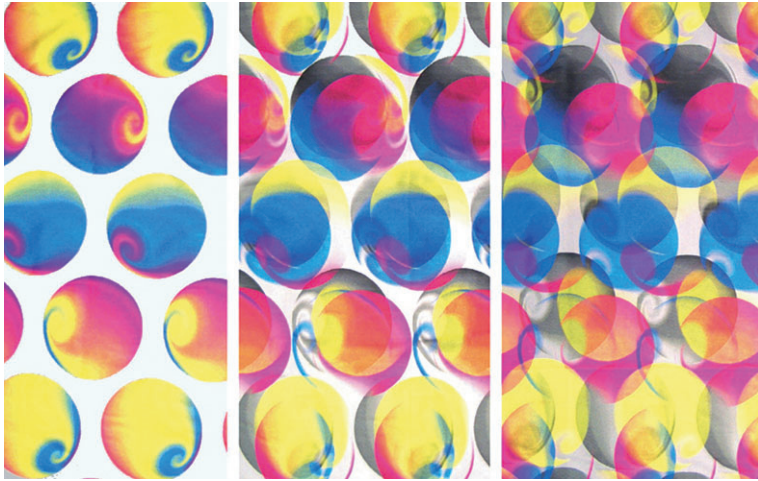


(b)

A3.3 Design creation with changeable colour layer effect (higher warp density)



A3.4 Design creations with moveable colour layer effect (lower warp density)



(a)



(b)

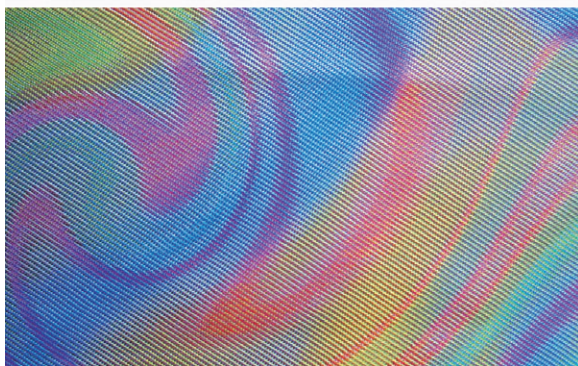
A3.5 Design creations from true-colour to black-and-white (higher warp density)



**A3.6 Design creation with figured shot-effect
(objective design with lower warp density)**



A3.7 Design creation with figured shot-effect (abstract design with higher warp density)



**A3.8 Design creation with figured double-face effect
(lower warp density)**



A3.9 Design creations with layer figured double-face effect (higher warp density)



(a)



(b)



**A3.10 Design creations with print-like effect
(silk design with higher warp density)**



(a)



(b)



(c)

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